THE HEAVENS & THE UNIVERSE

THE HEAVENS
AND
THE UNIVERSE

By

OSWALD THOMAS, Ph.D.

Professor of Mathematics and Physics Bundesrealschule and Bundesreformrealgymnasium, Vienna
Director Astronomische Zentrale für wissenschaftliche Liebhaberarbeit
Late Director Urania Observatory

Translated by

BERNARD MIALL

LONDON
GEORGE ALLEN & UNWIN LTD
MUSEUM STREET

The German original, "Himmel und Welt", was first published in Munich in 1928

Published in America under the title
HEAVEN AND EARTH

FIRST PUBLISHED IN GREAT BRITAIN IN 1930

PRINTED IN GREAT BRITAIN BY
UNWIN BROTHERS LTD., WOKING

PREFACE

"Nothing can console us for the Earth but the starry heavens!" But the Earth too is beautiful! On the fringe of the Wiener Wald a delightful path leads across the heath, the "Sommerheidenweg", and along this path I have been accustomed, for many years past, to lead my listeners on our astronomical night excursions. These listeners—invited to attend by advertisements in the Press—were always numerous; and on one fine June night no less than twelve hundred arrived: young and old, of both sexes, and of every station in life. We observed the stars; we imagined ourselves transported into the space of the universe; and often I continued my talks until the sun rose to greet us.

What I told my hearers, and how I told it, this book, with its sketches and diagrams, will now tell the reader. In these pages he will find much of what is known concerning the heavens and the universe.

OSWALD THOMAS

VIENNA, *the full moon before Easter, 1928*

CONTENTS

CHAPTER IV

CHAPTER V

CHAPTER VI

ILLUSTRATIONS

THE HEAVENS AND THE UNIVERSE

CHAPTER I

THE FIRMAMENT AND ITS FIERY SCRIPT

"ASTRONOMY is like a triumphal car. The two wheels are the great observatory and the library. Lacking either of these wheels, the car will capsize." So, many years ago, said one of the leaders of that science to which this book is dedicated, at a congress attended by learned men who had forgathered from all parts of the world in order to exchange ideas and discuss all sorts of astronomical problems.

I will ask my readers to imagine that they are assembled under the open heavens, far from the turmoil of cities: eager for knowledge, eager to become amateurs of astronomy. Above us, in the solemn stillness, is the dome of the summer sky. We are looking up at the stars, and we want to learn about them. Must we have an observatory and a library? Perhaps we can content ourselves more modestly with a spy-glass and a book. And where shall we find these two guides to knowledge?

We need not look long for them. We all have a spy-glass about our persons, a binocular, with which we can see the starry worlds at such a depth in the heavens that even the most vivid imagination can give us no real idea of their remoteness. This spy-glass is—our two eyes.

And where is the book, the great book? It lies open before us: it is—the starry heavens. Its fiery script is, indeed, not written in our alphabet. Its letters are points, lines, triangles, quadrangles, and intersecting circles. It is their language that we wish to understand.

And now we are ready to begin.

. . . . .

The distant meadows and a little wood divide the heavens from the earth, and we see the firmament as a vast *sphere*. But is not this an illusion? Are the heavens really spherical—are they not timeless and formless? We speak of the heavens and the wonders of the heavens. But what *are* the heavens?

We will put all dreams and imaginings aside—we will try to decipher the starry alphabet, and learn what it has to tell us. We are speaking now not of the heavens of the poet, but of the *astronomical* heavens, the most fundamental convention of an exact observation of the universe.

The astronomical heavens form a mathematically exact sphere, which we conceive as being described about us, so that its central point is in the eyes—or, to be more exact, in the right eye—of the observer. As to its radius, we will simply assume that it is very, very large.

Now, if this is so, the heavens of my neighbour cannot be identical with my own; but we always assume that the heavenly sphere is so large that it must seem quite indifferent to us whether we shift the centre ten yards or so in this or that direction. Compared with this

great assumed sphere, the whole earth on which we stand is only a *point.*

It may perhaps seem temerarious to define the heavens in so few words, and, indeed, so inexactly. In particular, it may seem a very dubious proceeding to begin the study of a noble science with a mere fiction, with a sphere which is merely "assumed". Let no one imagine for a moment that we are profaning a beautiful thing. Our astronomical firmament is nothing more than an eminently *practical*, though purely *imaginary*, instrument of the scientist and astronomer, by means of which he can define, with the utmost accuracy, the position of any point of the firmament: for example, the position of the Pole-star, or of the Great Bear, or of the red planet Mars, or the direction of the evening star which has but lately sunk beneath the horizon.

. . . . .

Were we to ascribe a definite and finite radius to the sphere of the heavens, we should be merely expressing the impression that is always received by an ingenuous observer of the firmament. Many years ago I made the experiment of asking a numerous audience of both sexes how high the sky *seemed* to them, with the remarkable result that a certain class of observer judged it—on an average, of course—to be only 624 yards above their heads!

This number, I need hardly say, is of no particular significance; even if we alter all three digits the result is essentially the same: the heavens *look* as though they

were only a few hundred yards above our heads. There is, therefore, a certain excuse for the fiction of a finite astronomical firmament. Our "heavenly sphere" is at least in accordance with our subjective experience.

On this "near" firmament—if for the time being we permit ourselves to call it "near"—we see many bright

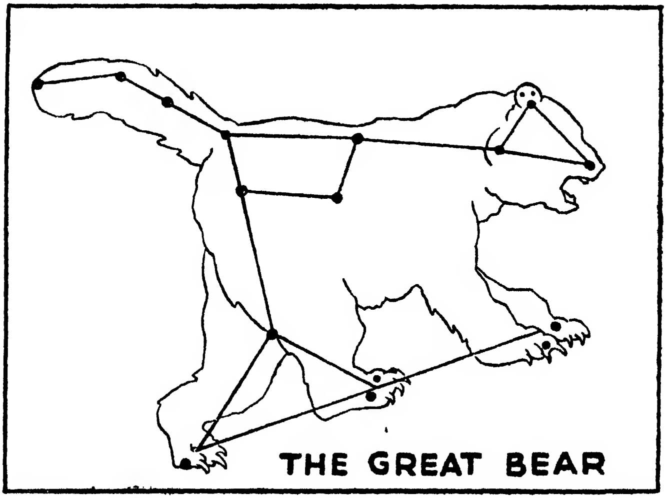

Fig. 1.—The Great Bear, showing the Plough.

points. You all know the seven stars of the Plough or Charles's Wain (Fig. 1). Four stars mark the corners of the actual body of the Wain or Plough. It is a trapezium. We may imagine the wheels as being placed at either end of the shorter parallel side. Continuing the longer side is a train of stars which follow a gentle curve; these are the broken poles of the Wain or the tail of the Plough. The outermost star is known as

Benetnasch, and the star at the angle of the pole is known as Mizar. If you have good eyes you may be able to detect, in the immediate neighbourhood of Mizar, a small companion star, the "Postillion", which has from time immemorial been a test of good eyesight.

. . . . .

The stars are divided into classes, according to their so-called *magnitude*. The very brightest are known as stars of the first magnitude; the stars in the Plough are for the most part of the second magnitude; the Postillion is a star of the fourth magnitude; and a particularly keen eye can detect even stars of the sixth magnitude. If you are able plainly to perceive more than one star inside the trapezium of the Plough you are able to detect stars of the sixth magnitude. The magnitude of a star has very little relation to its real volume or its actual brilliance: it is a measure only of its *apparent* brilliance.

Suppose we were to set up, in the open air, six electric lamps of varying brilliancy, which emitted, respectively, a light of

1, 2·5, 6·3, 15·8, 39·8, 100 candle-power,

and were to walk away from them until the brightest of them looked as bright as an average star of the first magnitude; then the series of six lamps would look like stars of the

6th, 5th, 4th, 3rd, 2nd, 1st magnitude.

As we shall see, if we consider the respective candle-

powers of the lamps which serve as comparisons, a star of any given magnitude is always about $2\frac{1}{2}$ times brighter than a star of the next magnitude below it.

. . . . .

The Plough or Wain is a part of the Great Bear. The longer side of the trapezium is part of the Bear's back, and if produced ends in the Bear's snout; the three stars of the pole or handle are the Bear's tail—the astronomical bear has a very long tail—while beneath the trapezium are three pairs of stars, one of which represents the fore-paws, and each of the other pairs one of the hind-paws.

There is scarcely a people on earth whose poetry does not somewhere contain a mention of the seven stars of the Plough. For the Romans they were seven draught-oxen, while the Arabs see the trapezium as a sarcophagus; the three stars of the pole are three sisters, mourning their dead brother, who lies in the sarcophagus. In America these seven stars are known also as the Big Dipper; but for Europeans they are the Plough or Charles's Wain.

. . . . .

Let us draw a straight line connecting the two stars which form the back of the Wain (Fig. 3). If we produce this line upwards, we shall find that they point to the Pole-star; they are indeed known as the Pointers. The Pole-star, as a bright star of the second magnitude, which has no other bright stars in its immediate neighbourhood, is easily recognized. It is

the brightest star in the Little Bear, and it marks the North.

Imagine a plumb-line suspended from the Pole-star. The point where the line would cross the horizon is the north point of the horizon, and directly opposite is the south point.

Now let us stand so that we see the Pole-star exactly in front of us. The west point of the horizon is then on our left, and the east point on our right.

What is the horizon? Roughly speaking, it is the line where earth and sky seem to meet. But we need a better definition than this; so we describe a horizontal plane, passing through our eye, and parallel to a surface of standing water. This plane, like every other plane that cuts through our mathematically exact heavenly sphere, describes a circle upon it. This circle is the real horizon, even though it may pass through the surrounding hills or trees. We might call it the true horizon, to distinguish it from the ordinary sky-line of the landscape.

Now let us determine the topmost point of the heavens. See if you can find a star which seems to you to be precisely overhead, at the *zenith.* And now let us verify this position with our telescope—that is, with our eye. It is mounted much like any other telescope. The ordinary telescope may be swung vertically upwards or downwards, or "in altitude", as the astronomers say. It may also be swung from left to right, or vice versa, which the astronomers call movement "in azimuth". We have only to nod the head in assent, and we are moving our natural tele-

scope "in altitude", while if we shake it in denial we are moving it "in azimuth".

Let us fix our glance upon the star which we take to be the zenith-star. We may rick our necks a little in doing so, but astronomy is an exacting science. Now, gazing fixedly at the star, let us turn slowly on our vertical axis. Some of us will find that they were mistaken; their star is by no means at the zenith, for they have to twist their necks in order to keep it in view. We will choose another star, and then a third, until we have found one that stands the test. We have now determined the zenith-point.

. . . . .

"The Pole-star is the only star that always remains in the same position, while the other stars move in circles about it, so that the whole heavens revolve." A little boy once read these words: he was then, I believe, eleven years old, and he was one day to become the librarian of the Empress Maria Theresa. Well, this little boy set out to find the curious star. He fixed a cardboard tube on a stand, and zealously observed star after star. But they "moved on"; they did not long remain within the field of the tube; until at last, after many trials of his patience, one docile star actually did remain within the field of view of this historic telescope; the boy had "discovered" the Pole-star. We can readily imagine the delight of our little astronomer—the joy of discovery. It is really a pity that we all of us already know the Pole-star.

. . . . .

Across the heavens we draw a semicircle from North to South. It passes through the zenith-point, and also through the Pole-star. This is the *meridian*. We mark the degrees upon it, from the north point of the horizon to the zenith—10°, 20°, 30°; in all, 90°. The height of the Pole-star above the north point of the horizon is easily determined. The geographical latitude of London is about 51°; that of Paris about 50°; that of Edinburgh 56°; that of Berlin about 52°. At each of these places the height of the Pole-star is just so many degrees above the horizon. If, for example, we were to go to the North Pole, whose latitude is 90°, the Pole-star would at the same time be the zenith star; while at the Equator our Pole-star would lie right on the horizon—at the "terrestrial" Equator, that is, for there is also a celestial Equator (it is shown by the thick curved line running across the two charts of the heavens on pp. 26 and 27). The celestial Equator runs directly from East to West, and is cut by the Meridian at its highest or *culmination* point.

The Pole-star enables us to determine the geographical latitude of our place of observation. A slight correction, indeed, is necessary, as our Pole-star does not remain quite exactly in the same spot. I am not referring to the fact that some 4,000 years ago it had a predecessor in one of the stars in the Dragon, while 12,000 years hence the brilliant Vega of the Lyre will have taken its place. These are changes which occur in the course of long ages, but which need not concern us to-day. I am referring to a very slight but perceptible change of position: the Pole-star is not precisely at the

pivot or polar axis of our heavenly sphere; like all the other stars, it is compelled to wander round the true Pole, though in ever so small a circle.

The sphere of the heavens, whose lower half we

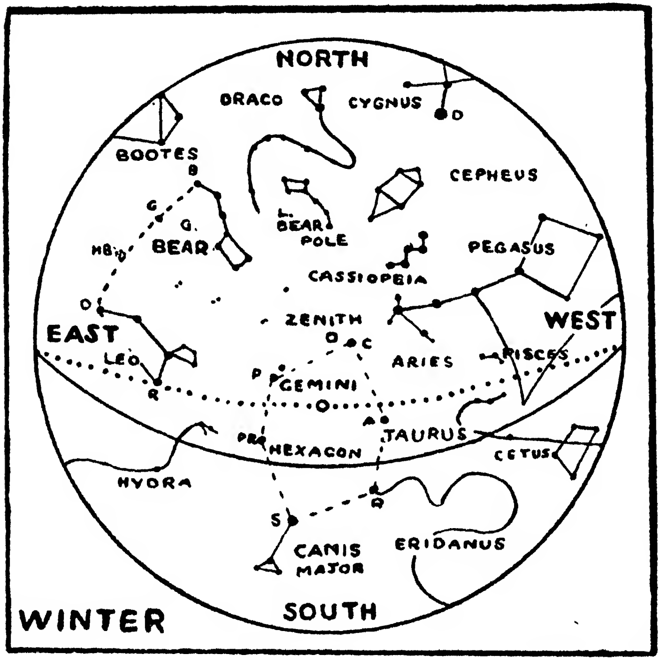

FIG. 2.—The Sky in Winter.

could observe simultaneously with the upper half if only the solid earth could be conjured away from under our feet, appears to be sown with innumerable stars. They seem as though fastened upon the dome of the heavens, and are known as *fixed stars*, because

they are fixed and unchanging in their relative positions, forming an eternal adornment of the beautiful sphere of the firmament. As a matter of fact, they all move along their individual paths, but it would be

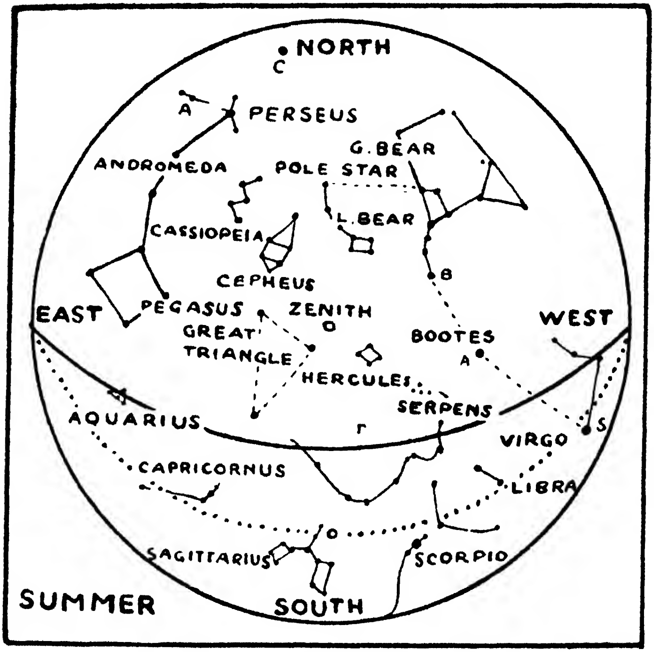

FIG. 3.—The Sky in Summer.

thousands of years before their change of position would be perceptible to the naked eye. It is therefore possible to combine conspicuous groups of stars, like the seven stars of the Plough, or the larger group of the Great Bear, into star-pictures or *constellations*.

Our two charts of the heavens in summer and winter are not intended to take the place of star-maps or astronomical charts, but merely to show, approximately, the relative positions of the constellations.

If, starting from the corner of the Wain to which the pole is attached, we draw a straight line through the Pole-star, there, about 30° beyond the Pole, we shall come to the great "W" of Cassiopeia.

It is an easy matter to measure or to estimate 30°, or any other number of degrees, on the sphere of the heavens. We can thus measure the distance in degrees between one star and another, or the length, for example, of the shorter side of the trapezium in the Plough. Hold out your right hand at arm's length and separate your thumb and middle finger until the tip of the thumb "touches" the one star and the tip of the finger the other. Now, taking care that you do not alter the distance between thumb and finger, bring your hand nearer to your eyes and estimate this distance in centimetres. It is, we will say, 8 centimetres. Now as luck will have it, 8 centimetres, if held up against the sky—at arm's length, of course—cover almost precisely 8°. This gives us a simple rule: 1 centimetre at arm's length corresponds to 1°.

Our "observatory", you see, is becoming more and more complete. We began with a telescope—our eyes; for the mounting of the telescope we had the muscles of the head and neck. When we were looking for the zenith-point we were able to rotate it round a vertical axis. Now we have an instrument for measuring angles

—the right hand at arm's length, and our device of measuring the degrees of the heavens with a centimetre rule.

. . . . .

We have been standing for some time on the same spot. It has been growing darker. We have the impression that the heavens are motionless—until we begin to reflect. Have not new stars risen in the east and south-east, and has not the Plough altered its position? Of course this is so. We can, as a matter of fact, readily convince ourselves that the whole firmament rotates like a rigid sphere about a rigid line. This line runs from our eye to the true pole of the heavens, and is known as the *celestial axis*. It must be imagined as protracted through the earth.

If we do not want to wait for hours on end in order to convince ourselves of the rotation of the firmament, we can perform a very simple experiment, which does not require even the historical card-board tube. And this experiment may be carried out in the city even better than in the open country. The houses, walls and lamp-posts are suddenly converted into astronomical instruments. We select a star in the East, and stand in such a position that it is just, and only just, concealed by the point of a gable-end of a neighbouring house. We count—one to ten; and behold, the star "rises". We walk towards the East, approaching the house only by a few inches, till the star is once more covered by the gable. Hardly have we reached the new spot when the star rises again; and so forth. Meanwhile,

in the West, the stars are setting. We are convinced of the rotation of the heavens.

. . . . .

The time between the setting of a star and its next setting on the following day, or the time between the *transit* of a star across the meridian-line and its next meridian transit, is known as a stellar or *sidereal* day.

The revolution of the heavens proceeds with a uniformity which, ever since man was capable of thought, has been regarded as the ideal of all uniformity. It is still so regarded to-day. While in all science we accept, on principle, the fiction of uniformity, and apply it with great advantage to the description of natural process and technical method, we are nevertheless compelled to admit that in the last resort such things as "constant" values, constant directions, constant quantities, constant masses, constant periods—like that of the rotation of the starry firmament on the celestial axis—cannot really exist.

Laplace believed that a variation in the length of the stellar day was possible, but it is only in our days that Innes has succeeded in demonstrating a certain minimal variation, though the period of the variation is indefinite. The variations are so infinitely small that we shall merely note their existence; practically they do not concern us. For us the revolution of the heavens remains the ideal of uniform rotation.

. . . . .

We have just seen the Pole-star, the Plough, and the

capital W of Cassiopeia. In our latitudes these constellations never sink below the horizon; they are "circumpolar" constellations. We might choose any one of their stars as the pointer of a great heavenly clock, the Pole-star marking the pivot of the pointer. And as a matter of fact the astronomers do tell the

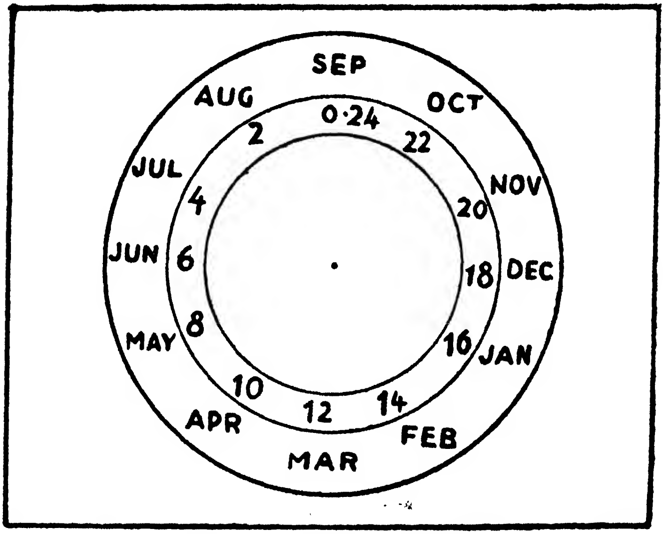

FIG. 4.—A Perpetual Clock.

stellar or sidereal time from the position of the stars; and in the following manner:

We must imagine a great circle described in the heavens about the Pole-star or the Pole as centre; a stupendous dial, large enough to include the Plough and the W of Cassiopeia (Fig. 4). This dial, which is immovable, is divided into 24 equal parts; and at the

top of the dial, some 30° above the Pole-star, we must imagine the figure 0. To the left of the Pole, precisely on the line running from the Pole to the west point, is a 6; directly beneath the Pole is a 12; and to the right of the Pole an 18. And overhead, where the 0 stands, we must also imagine a 24.

For sufficient reasons we shall choose for our pointer or hour-hand the line joining the Pole with the *colure-star*. This is the last star in the capital W of Cassiopeia. Just where we should lift our fiery pen from the heavens in writing this W is the point of the hour-hand.

The name of this star is derived from the *colure line*, which passes through the Pole and the last star in the W of Cassiopeia. Literally translated, it has not a very celestial sound, for it means "tail-cutter", because on the old star-maps this line just cuts off the tail of the Great Bear. However, we are quite free to forget this derivation.

The firmament, including the capital W, rotates without intermission. If the colure-star stands over the Pole-star, the astronomers say: "It is 0 (or 24) by star-time." If the colure-star is on the left of the Pole, it is 5, 6, or 7 by star-time. A little practice, and we shall understand how to "tell the time by the stars". If the colure-star is under the Pole, it is 12 o'clock, and so on.

. . . . .

Stellar or sidereal time is determined by the stars; solar time by the Sun. It is 12·0 noon by solar time when the Sun has reached its highest position; that

is, when it crosses the meridian. We will assume that we possess an ideally perfect watch, which does not lose or gain a second in a century. If with this watch we measure the time of the Sun's transit from one day to the next, we shall find that our Sun has his caprices, for sometimes he travels faster than at other times. The astronomers call these caprices the *time equation*. In order to get round them, the conception of a *mean sun* has been introduced; a sun which moves as regularly as the hour-hand of our ideal watch. When this fictive sun stands exactly in the south, it is noon by the mean time, or 12 o'clock *local time.* We will count this local time from 0·0 midnight to 24·0 midnight.

. . . . .

Our perpetual clock (Fig. 4) should enable us to tell the local time from the stars. The two concentric dials are intended merely to illustrate a principle, and are therefore only roughly divided, and this division holds good only for the days about the 21st of each month—that is, for the latter half of each month. Now, suppose to-day is October 21st. In the heavens, with the help of Cassiopeia, we read "4 o'clock star-time". Now let us look on the outer dial for "October". It stands beside the figure 22. Add this 22 to 4, and we have 26 o'clock —that is, 2·0 a.m. local time.

Another example: It is August 21st. We see by the sky that the stellar time is 20 hours. Under August is the figure 2; 20 plus 2 gives us 22 hours local time —that is, 10.0 p.m.

In everyday life we have long since given up using local time. For practical reasons we reckon the same time for considerable areas of the earth's surface, although in different parts of these areas the Sun will cross the south meridian at quite different times, so that these localities will have different local times. We call this sort of time *zonal time*. Germany, for example, has adopted Middle European time, which is an hour later than West European or Greenwich time, and an hour earlier than East European time. We must leave it to the reader to convert the local time as told by the stars into Greenwich time. He needs only to know the geographical longitude of his locality.

. . . . .

It would simplify matters greatly if the 24 sidereal hours coincided with the 24 hours of our everyday time. But this, as we have seen, is unfortunately not the case. Owing to this lack of correspondence, the face of the heavens changes as the weeks and months go by, so that each season of the year has its own particular sky. The mark of the winter sky is the constellation of Orion. It may be recognized by the three stars of Orion's belt—the balance-beam of the Arabian astronomers (Figs. 2 and 5).

The brighter of the two shoulder-stars, a red star, is Betelgeuse (B.); the brighter of the knee-stars, a white star, is Rigel (R.). This latter star, together with five other brilliant stars—namely, Sirius (S.) in Canis Major, Procyon (Pr.) in Canis Minor, Pollux (P.) in Gemini, Capella (C.) in Auriga, and Aldebaran (A.) in

Taurus (see Fig. 2)—forms the "Great Hexagon" round Orion. Sirius was the sacred star of the Egyptians, whose priests gave it a solemn greeting at the season

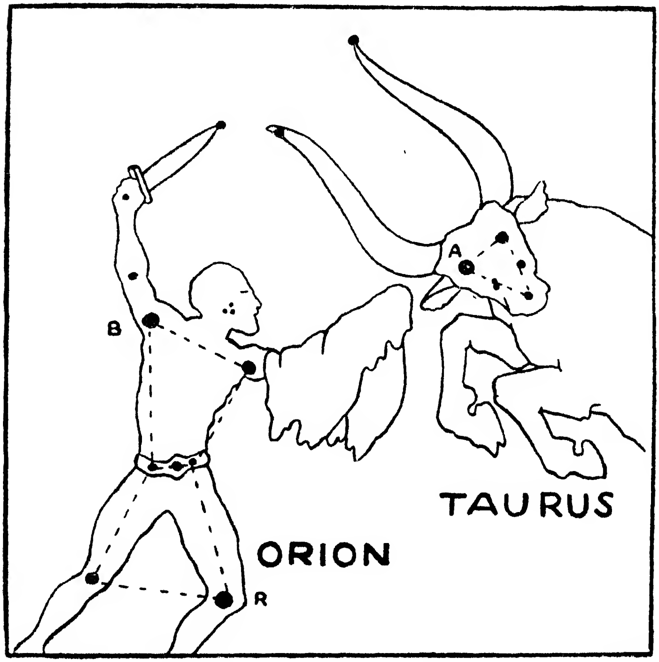

FIG. 5.—Orion and Taurus.

of each year when it appeared in the morning sky after a long period of invisibility.

The summer sky reveals a magnificent *triangle* in the midst of the Milky Way (Fig. 6); at its angles are three stars of the first magnitude. Its brightest star is Vega (v) in the Lyre. If we look overhead on a summer

night we shall see it near the zenith; it is the brightest star in the whole neighbourhood, white as an arc-lamp, with just a shade of blue; it is unmistakable. Beneath

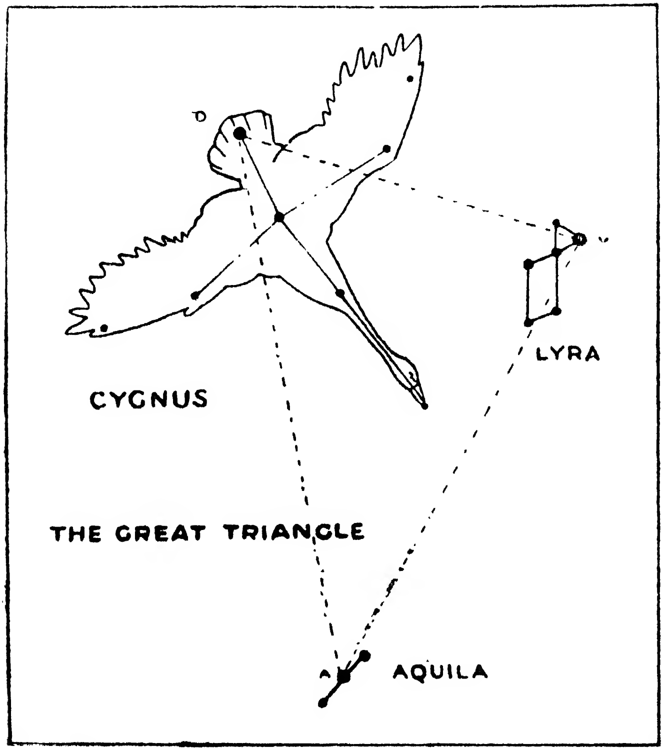

FIG. 6.—The Great Triangle: Vega-Deneb-Altaïr.

it are three stars in a row; they form part of the constellation of Aquila (the Eagle), and are sometimes called the Sceptre. The bright central star is Altaïr (A.).

Just where the Milky Way is cleft in two is the third star of our summer triangle; it is Deneb (D.) in the Swan, which is sometimes called the Northern Cross, to distinguish it from the Southern Cross, which in our latitudes is invisible.

We must not forget a fine garland of stars which on July evenings may be seen in the North-East, but which is visible elsewhere for the greater part of the year: it is a chain of five stars, the three central stars being in Andromeda, while of the stars at either end of the row one is in Perseus and one in Pegasus (Fig. 3).

The constellation of Perseus is famous for its swarm of meteors, the Perseids, which in August appear as "shooting stars". These are dark, cold bodies, often only a few ounces in weight, which fly through space in countless swarms; they are also known as meteorites. When their course is interrupted—as happens, for example, every August—by the atmospheric envelope of our earth, they are heated to incandescence, and appear as meteors or shooting stars. If they are particularly brilliant they are sometimes described as fireballs.

. . . . .

The stars are in reality nothing else but suns, as large as our own Sun, and often very much larger; and as hot as our Sun, or even hotter. It is only on account of their stupendous remoteness that they appear to us as little points of light.

Hitherto we have intentionally conceived of the stars as merely projected on our fictive spherical firmament; but what is their real distance?

Astronomers, like other people, reckon in miles or kilometres, but if we were to reckon the distance of the stars in miles, we should have such endless rows of figures that although we could write them or express them in words they would really be absolutely incomprehensible. We have, therefore, to find some other means of expressing the remoteness of the stars.

Suppose we are walking across country, and meet another pedestrian coming towards us. We ask him how far it is to the village yonder. He tells us that it is so many miles; and then we know where we are. But he may possibly tell us that it is "an hour farther". He mentions a period of time, but we understand him well enough: he means the distance which we should cover in an hour's walking, and we are quite satisfied with this answer.

The astronomer too appeals to a wanderer, with whose help he is able to measure distances in space. This wanderer, however, is not a pedestrian, but the swiftest messenger in the universe: *light*, the ray of light that in a single second travels 300,000 kilometres (186,000 miles): that is, a distance seven or eight times the circumference of the world (Fig. 7).

How far is the Moon from the Earth? Rather more than one "light-second". That means that a signal, a flash of light, would take rather more than a second to reach the Moon from the Earth. And how far is the yellow Altaïr in the Eagle?—The astronomers call it one of the nearer stars. It is "only" sixteen light-years distant. How many seconds are there in sixteen years?—So many times is Altaïr farther from us than the Moon.

A light-year is not really a year, but the distance covered by light in a year. Expressed in figures, it is about 10 billion kilometres, or nearly $6\frac{1}{4}$ billion miles.

Vega is twenty-six light-years distant, while the distance of Deneb in the Swan is not less than six hundred light-years, and possibly very much more. Yet still we have by no means reached the confines of the universe. The Milky Way itself is merely a cloud of stars; for the most part they are so remote from us that their light must travel for thousands of years before it reaches our solar system.

. . . . .

I cannot here give you a list of all the constellations, but I should like to point out the constellations of the Zodiac. It is now July, and in the calendars and almanacs, or on old sundials, you will find the Lion as the "sign" of July. Quite apart from all historical reasons, it is of some practical use to know that in July, directly after sundown, we shall see the Lion setting in the western sky. In the month of July it is the Sun's close neighbour, and follows fast upon his heels. In form it consists essentially of two trapeziums, the larger forming the body and the smaller the head. The brightest star in the great trapezium is Regulus, the King-star. All the other months have their constellations likewise, and these constellations as a whole are known as the Zodiac, or the Zodiacal belt, for they form a belt round the heavens (Figs. 2 and 3). In all we have twelve such constellations: the Ram (March), the Bull (April), the Twins (May), the Crab (June),

the Lion (July), the Virgin (August), the Balance (September), the Scorpion (October), the Archer (November), the Goat (December), the Water-Carrier (January), and the Fishes (February). (Or, to give them their Latin names, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, and Pisces.)

. . . . .

To-night, low in the south-western sky, we can still see a few of the stars of the Virgin. Its brightest star, Spica, may be found by producing the tail of the Bear, the connecting-line passing through Arcturus, a brilliant star in Boötes, known both as the Ploughman and the Bear-driver.

In the Golden Age, old legend relates, the Virgin used to dwell with mankind. In the Silver Age she showed herself more rarely, and now she is seen only in the fields of heaven, far from the eyes of profane humanity. She shows herself only to the few whose hearts and minds are attuned to our beloved stars.

The Balance consists essentially of two stars of the second magnitude. Then comes the Scorpion, with Antares = Anti-Ares, the pendant to Ares, or Mars. It is as red as Mars, and is really larger than all the other stars. To the left of the Scorpion is the Archer, in the brightest part of the Milky Way.

The figure of the Goat consists essentially of two stars one above the other; and on closer examination the upper star reveals itself as a double star. The Water-carrier may readily be recognized by the Urn or

Pitcher, a small equilateral triangle with the point of gravity in the centre (Fig. 10).

The other signs of the Zodiac are invisible to-night; the next in order is the Fishes. This constellation is notable chiefly for a great emptiness. The Fishes are followed by the Ram, the sign of March, a pair of stars with a third, fainter companion, which appears double when seen through a telescope. The Bull, in which we see Aldebaran, is distinguished by two bright groups of stars, the Hyades and the Pleiades. The Hyades are the stars in the Bull's head (Fig. 5), and are also known as the Rain-stars; while the Pleiades are known also as the Seven Sisters, or the Hen and Chickens. The Hyades and Pleiades are the two pillars of the "Golden Gate". Of the Twins (Gemini) we have already spoken. Their brightest star, Pollux, is a corner-star of the Great Hexagon round Orion. The second brightest is Castor. The Crab, between the Twins and the Lion, is quite insignificant. It contains a group of stars in the neighbourhood of two modest looking stars; and these are known as "the Crib and the Foals".

CHAPTER II

THE SUN AND THE EARTH'S MOTION IN SPACE

It is only a little more than a century ago that one of our best astronomers, William Herschel—who was first of all a musician, then an amateur astronomer, and finally Astronomer Royal in England—quite seriously believed it possible that the Sun itself might be a world, which might even be a dwelling-place of human beings. The Sun would in all conscience be large enough, for it is more than a million times as large as the Earth. Dark clouds within the body of the Sun were supposed to protect the inhabitants from its burning shell. We know to-day that the surface of the Sun is at a temperature of 6,000° C., and that the temperature of the centre of the Sun is supposed to be about 70,000,000° C. There can be no life in the Sun—no life in the ordinary sense of the word. But is the Sun therefore dead? Can we speak of a dead mass when energies of many millions of degrees are at work? No; the Sun does not merely radiate light and heat, does not merely beget life on our Earth; the Sun *is* life.

Let us in imagination make the journey to the Sun. The flash of a cannon would take about eight minutes to cover the distance of 93,000,000 miles; the same flash of light which travels 186,000 miles between the two ticks of a seconds pendulum, which in one second might be reflected between seven and eight times round the Earth.

The shell fired at the Sun by our cannon would have to travel for nine years at its initial velocity before it would plunge into the envelope of the Sun, and the report of the discharge, travelling more slowly than the shell, would not arrive until fourteen years after the firing of the gun—supposing that the air which conveys the sound were not confined to the neighbourhood of the Earth, but were to fill the empty space between the Earth and the Sun. And—setting all "ifs" aside—how long would it take to reach the Sun in a railway-train?—Just about 400 years. We take our seats to-day in the Sun Express, *via* the Universal Ether. Speed of journey, over 600 miles a day! We set out to-day, a party of curious travellers, and our great-great-great-great-great-great-great-great-great-great-grandchildren alight from the train. Ten "greats": twelve generations take part in the journey, and the twelfth arrives at the destination. That is how far the Sun is!

. . . . .

The Sun is 93,000,000 miles from the Earth. It is, of course, quite impossible to conceive any real idea of this enormous number of miles, and even if we think of a projectile or a railway-train we still have figures which are simply incomprehensible numbers. We must find some other way of realizing the distance of the Sun. If our Earth were reduced to the size of a hazel-nut, the Sun would be a ball whose diameter would be about that of a large coach-wheel. Let us imagine that we have a model of the Sun, which is precisely

4 feet 6 inches in diameter, and a model of the Earth ½ inch in diameter; then all the dimensions will be 1,000,000,000 times reduced.

Let us for convenience convert these dimensions into millimetres. A millimetre in the model represents a reality of a milliard millimetres, a 1 with 9 noughts; that is, 1,000,000,000 millimetres, or a million metres, or a thousand kilometres. The 13 millimetres of the model Earth will therefore correspond to a reality of 13,000 kilometres, which is the actual diameter of the Earth.

One metre in the model of the Sun represents a reality of 1,000,000,000 metres, or a million kilometres, so that 1·39 metres would represent 1,390,000 kilometres, which is the diameter of the Sun. We shall often make use of this "milliardth measure", which we shall call the *planetary scale*; and once for all we will note that

> 1 mm. in the model is in reality 1,000 km.
> 1 m. in the model is in reality 1,000,000 km.

This little Earth revolves upon its axis once in twenty-four hours, which in our model would be a movement so very slow as to be hardly preceptible; yet in reality any spot on the surface of the Earth in the neighbourhood of the Equator is whirled round the axis of the Earth at a speed which can only be compared with that of a cannon-ball.

The Earth rotates from West to East. Of this movement we of course perceive nothing; but we know that all movement is relative, so that we can equally well

say, if it suits our purpose, that the heavens—in relation to our Earth, and as our own eyes tell us—revolve in the opposite direction. In other words, the rotation of the heavens is, so to speak, a reflection of the rotation of the Earth.

The Earth is a spinning-top, which, like any other spinning-top, had once to be set going. It was very many million years ago that the ball of the Earth, knitting itself together out of the hot stuff of the Sun, began to spin in the same direction as it is spinning to-day, and it so chances that the axis of the Earth points at the present time to a star in the constellation of the Little Bear, which we call the Pole-star; since it lies, approximately, at the "pole of the heavens", which does not partake of the revolution of the firmament.

The Earth moves in a circle round the Sun, at a speed of 30 kilometres, or rather more than 18 miles per second, completing the circle in a period of 365 days, or a year. We are as little conscious of this journey round the Sun as we are of the rotation of the Earth; yet this movement also is reflected in the stars.

Let us imagine that we are walking round a circular room, containing twelve doors, in the centre of which room is a lamp, at about the height of our eyes, which represents the Sun. At one moment we shall see this lamp in front of the first door, then in front of the second, the third, the fourth, etc. Let us imagine that on one of the doors there is painted a ram's head, on the next a bull, on the next a pair of twins, followed by a crab, a lion, a virgin, a balance, a scorpion and

an archer, a goat, a water-carrier, and lastly some fishes: then, by walking round the lamp, we shall understand how the Sun, from month to month, is projected upon the different constellations of the Zodiac. The signs of the Zodiac are his monthly stations. To us it appears as though the Sun travels along the Zodiacal belt.

The stars shine by day as well as by night, but the dazzling light of the Sun outshines them so long as it is above the horizon. Consequently, apart from the rare moments of a total eclipse of the Sun, it would seem that we cannot possibly tell through which of the signs of the Zodiac the Sun is passing.

Yet if, evening after evening, we observe the constellations shortly after sunset, and note which of them are following the Sun, and if, in the early morning, just before sunrise, we note the stars which are preceding the Sun, we shall find that we are able to mark the position of the Sun, week by week, on a star-map, and in this way we shall find that the path of the Sun through the heavens does actually lie along the Zodiacal belt. The path followed by the Sun is known also as the *Ecliptic*—that is, the "line of eclipses"—because eclipses of the Sun and Moon always occur at some point or other on this line. The Ecliptic, like the Equator, is one of the "great circles" of the heavenly sphere, and cuts across the Equator at an angle of $23\frac{1}{2}°$, which we call the "obliquity of the Ecliptic". The two points where it cuts the Equator are known as the *Spring equinox*, in the constellation of the Fish, and the *Autumn equinox*, in the constellation

of the Virgin. The two points of the Ecliptic which lie half-way between these two points of intersection —one of them $23\frac{1}{2}°$ above the Equator, and the other as many degrees below it—are the *Summer solstice* in the constellation of the Twins and the *Winter solstice* in the constellation of the Archer. Whenever the Sun, in the course of his year's journey, arrives at one of these points, a new astronomical season begins.

. . . . .

On March 21st the Sun arrives at the Spring equinox, the point where the Ecliptic cuts across the Equator; it then rises in the East at precisely six o'clock, reaches the culmination of the Equator at noon, and sets at six o'clock precisely in the West. It is twelve hours above the horizon, and twelve hours beneath it; the day and the night are of equal length.

On June 22nd the Sun arrives at the Summer solstice, $23\frac{1}{2}°$ to the north of the Equator, so that at midday, when it reaches the meridian-point, it stands $23\frac{1}{2}°$ above the culmination of the Equator. Its daily path is therefore very much longer than in Spring; for it is not now a semicircle of 180°, along which the Sun travels in the space of twelve hours, but approaches more nearly to a full circle, and the further north the position of the observer, the more closely its path approximates to the full circle. If, for example, we were on Spitzbergen, within the Arctic Circle, the path of the Sun would cover the full circle of 360°. It would then be twenty-four hours above the horizon; in other words, it would still be shining at midnight. At the

North Pole, indeed, for a period of six months the Sun never sets: from the beginning of Spring to the beginning of Autumn. By September 23rd the Sun has once more reached the Equator, and stands at the Autumn equinox. The length of the day and the night

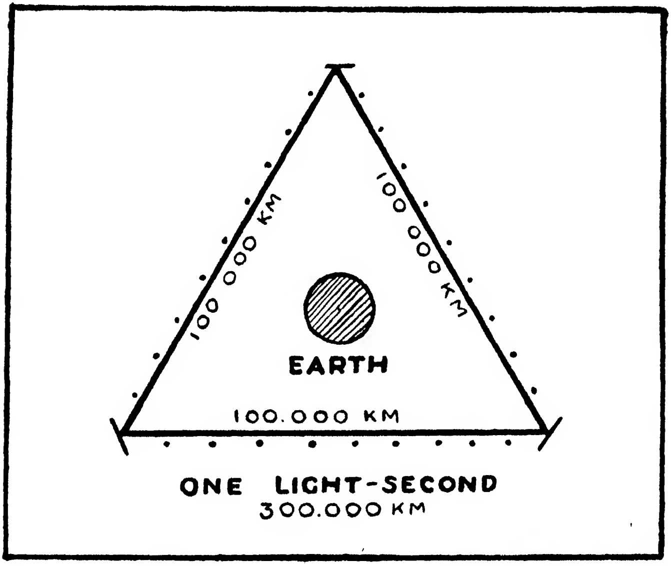

FIG. 7.—A Light-Second, compared with the diameter of the Earth.

are now the same as on the first day of Spring. Now the Sun passes into the Southern hemisphere, and its height at midday is less every day.

On December 22nd the Sun is $23\frac{1}{2}°$ below the culmination of the Equator, so that in the Arctic Circle it can only just be seen at midday.

If we are in the neighbourhood of the terrestrial Equator, the celestial Equator will rise vertically from East and West, so that the Sun will pass through the zenith point twice a year: once in Spring and once in Autumn; while for observers situated on one of the tropic lines it will pass through the zenith either in Summer or in Winter.

. . . . .

We know why the length of the Sun's path differs at different times of the year. Our Earth rotates upon an axis which is inclined at an angle of 66½° to the plane of the Earth's orbit, but this axis is, so to speak, always parallel to itself, so that it points always to the same spot in the heavens, to the Pole-star. Sometimes, therefore, the North Pole of our Earth is turned towards the Sun, and then it is Summer in all the countries about the Pole, including the whole of Europe. Six months later the North Pole is turned away from the Sun, and all the countries that lie about it, including Europe, pass through a cold, dark season. On the terrestrial Equator the day and night are of practically equal length all through the year.

. . . . .

Every moment, as we are speaking, the spot on which we are standing is whirling round the axis of the Earth; and every second the whole Earth travels 18 miles through space, moving in a circle round the Sun.

But the Sun itself is not motionless in space. Let us

go into the matter a little more deeply, and let us call to our assistance a little *relativity*. And there is no need for alarm; the matter is really quite simple. Here is a match-box, which I have taken from my pocket. It has the same shape as my room, only it is smaller. I am now pointing to one of the eight corners of the box. At this corner three surfaces meet. We will cover these three surfaces with white paper. Inside the box is one match. I lay the box on the table. The match is now at rest. To be more exact: the match is at rest "in relation to the box, or in relation to the three white surfaces", and I will confirm this observation by pedantically convincing myself that the distance of the head of the match from the three surfaces does really remain unchanged while I am looking at it. Now I shake the little box. Is the head of the match at rest now? It is in movement; but I will purposely be more exact: it is in movement "in relation to the box", for its distance from the three given surfaces, which form our standard of reference, alters as I shake the box.

"Yes, but is not the match in movement in relation to the room likewise?"—That question really needs no answer; for I conclude, from your using the words "in relation to", that you have understood what I am driving at; you will now understand what the modern doctrine of movement means when it speaks of "rest" and "motion". These words have an exact meaning only if we explain to what surroundings we are referring the state of rest or motion. Our match, for example, when it lies in its box, and the box lies on

the table, is at rest with reference to the box, and also with reference to the table, and the room, and the whole earth; but it is not at rest with reference to the motor-car which is rushing past the house. I squeeze the match-box into my waistcoat-pocket, behind the notebook which is already there, and I sit down. Is the box now at rest?—The question is not sufficiently exact. We have not made the all-important reference. It is "at rest" in relation to my chair, but what if I stand up and walk to and fro? Is the box at rest now?—The answer is that it is in movement in relation to the room, for its distance from the walls of the room, and perhaps from the floor as well, is continually varying. At the same time, the box is relatively at rest in relation to the notebook which is next to it in my pocket. Now I dance and leap into the air. Is the box still at rest? It is still completely at rest in relation to my notebook. All movement and all rest are only *relative*.

. . . . .

And now to return to the Sun!—This illustration of the match-box has taught us to be more exact in our manner of expressing ourselves. The Sun, by itself, were it ever so large, would be neither moving nor at rest if there were nothing else in the universe to which the movement could be referred. We look up from the little Earth and seek a larger "frame of reference" outside it: to the "walls of the room" in the universe in which the Sun is shining.

We know that the stars are distant suns, sisters of our Sun, far away in space. We can regard these stars,

as a whole, as the bodies to which we can refer our Sun.

William Herschel would not have been the great man he was if he had bequeathed to us only his ideas concerning the highly problematical inhabitants of the Sun. As a matter of fact, it was he who solved the problem of the motion of our Sun. In relation to the distant stars, the Sun is in constant movement. It is hastening with a speed of more than 12 miles per second in the direction of Hercules, a constellation not far removed from Vega in the Lyre. This constellation is famed for its globular cloud of stars, which appear to the naked eye as a speck of light, but in the telescope as an assemblage of innumerable stars. The constellation of Hercules is, so to speak, the future home of our solar system.

But perhaps the calculations of the astronomers are not quite accurate? Perhaps the Sun, together with our Earth, is rushing straight at that bright, beautiful star in the neighbourhood of Hercules—at Vega in the Lyre? Already we foresee a catastrophe, the conflagration of the solar system!—No, we have plenty of time. Quite apart from the fact that Vega lies rather to one side of our trajectory, it is, like our own Sun, and like all the suns in the universe, itself in motion. But we can find comfort in our old friend the multiplication-table. To begin with, Vega is twenty-six light-years distant from us.

Its light travels towards us at the rate of 186,000 miles per second. We, on the other hand, are moving towards the star at the rate of only 12 miles per second;

that is, our speed is fifteen thousand times as slow as that of light. Consequently we should reach the star not in twenty-six years, but in 15,000 times twenty-six years: that is, in about 400,000 years.

. . . . .

Even as I am speaking to you the globe of the Earth is whirling us round the Earth's axis; secondly, it is carrying us with it as it glides on invisible leading-strings round the Sun. And thirdly—and perhaps not lastly—the Sun is flying towards the stars in Hercules at the rate of 12½ miles per second, 750 miles per minute, 44,930 miles per hour, 1,078,320 miles per day, or 393 million miles in the course of the year.

I take a round stone—which you may imagine to be the Earth—tie it to a string, and whirl it in a circle round my hand at the end of the stretched string. My hand is the Sun, and the string represents the mysterious force with which the Earth and the Sun attract one another, in such wise that their mutual distance always remains the same. There is no reason why I should not swing the stone so that the plane of its orbit is vertical. Now, still swinging the stone round my hand, I run straight ahead in a given direction. The stone is now describing a spiral; it is following a corkscrew path. And seen from the distant stars the path of the Earth would appear as such a spiral.

Let us now turn to our milliardths measure. The Sun is a ball 55 inches in diameter; the Earth, as large as a hazel-hut, revolves about it at a distance

of 160 yards. While it makes one revolution round the Sun, the Sun itself has moved 690 yards obliquely to the plane of the Earth's orbit. We thus obtain a corkscrew line, and the ratio of the diameter of the spiral to its length, measured on the slant, is about 1 : 2.

Such is the singular path of our great little Earth through space. Yet we have been taught that the Earth moves in a circle round the Sun. What is the truth? Of course, both statements are true. All paths, like all motions, are only relative. If we disregard the movement of our Sun on its own axis, and also its flight through space in the direction of Hercules, and describe matters only relatively to the Sun, then the Earth moves round it in a circle. (More accurately speaking, of course, the orbit of the Earth is an ellipse, but it is such a "corpulent" ellipse that it can hardly be distinguished from a circle. We once cut an ellipse out of white paper, so accurately that it corresponded exactly to the shape of the Earth's orbit. At the same time, care was taken to avoid any indication of the longer axis of the ellipse, and it proved to be very difficult to hold it against the blackboard so that its "length" was horizontal.)

Thus, while for certain purposes it is permissible to say that the orbit of the Earth is an approximation to a circle, it is in actual fact an ellipse, which, relatively to the stars, is drawn out into a spiral.

. . . . .

An *ellipse* is easily described. Hold up a coin before your eyes. If the line of sight is not absolutely at right

angles to the surface of the coin, its circumference appears as an ellipse, and the more slanting the coin, the slenderer the ellipse. The method of drawing this closed curve is as follows: We lay a loop of thread on a drawing-board, and thrust a needle into the board inside the loop. Now, with a pencil, we stretch this loop until it becomes a double thread, and if we move the pencil round the needle, keeping the thread stretched, we shall describe a circle. We repeat the procedure, but now, instead of one needle, we will have two, fixed within the loop at two different points

LI·GHT·YEA·RME·ANS
10.000.000,000.000
KILOMETRES

FIG. 8.—How to remember the length of a Light-year.

of the drawing-board; the curve described is now not a circle, but an ellipse, and the greater the distance between the positions of the two needles, or the *foci* of the ellipse, the narrower will be the ellipse. Now draw a line from end to end of the ellipse, passing through the two foci. This is known as the major axis of the ellipse. If we draw a line at right angles to this axis, and passing through its middle point, we have the minor axis.

. . . . .

Just as it is really quite permissible—so long as we remember the actual facts—to say that the orbit of

the Earth is a circle, so we need not hesitate to say that the form of the Earth is a sphere. If we look into the matter more closely, we shall find that it is slightly flattened at the Poles; but here again, if we were to make a model of the Earth which exactly reproduced the natural proportions of the globe, we should hardly be able to detect this flattening. In the second approximation the Earth is a so-called *ellipsoid of rotation*, which is attained by rotating an ellipse on its minor axis. In reality the Earth only approximates to this form also. The form of the Earth may be rather more accurately described by defining it as a *geoid*, a body in which the force of gravity acts always precisely at right angles to the surface, and in which all the seas of the Earth are imagined as being connected by channels. This geoid is, of course, merely a fiction; the Earth is a geoid, yet in the last resort it is not even a geoid: "The Earth is the Earth" is the final conclusion of all our wisdom; unless indeed a pessimist should dispute even this, pointing to the fact that the Earth of to-day is no longer the Earth of yesterday, and, indeed, that the continual transformation of the Earth's surface by water, wind, and the internal forces of the globe, to say nothing of its human inhabitants, makes all attempts to arrive at an exact expression of the form of the Earth illusory. But such wisdom is a dead wisdom, and "error alone is life".

. . . . .

Here we are, wandering round the Sun. It is so distant that if we could go thither by rail it would take us

four hundred years to reach it, and it is so large that our train would take twelve years to travel once round its surface. The diameter of the Sun is more than a hundred times that of the Earth. The body of the Sun consists of the same elements as those which we find upon our Earth, yet its density is only one-fourth the density of the Earth. But despite its comparatively light mass, the Sun weighs 330,000 times as much as the Earth. The "weight" of the Sun amounts to two quintillions of kilogrammes—a 2 followed by 30 noughts; or roughly two thousand million million million million tons.

Every mass has the property of attracting every other mass. This force, whose nature will be considered later, is simply the "weight" of the body attracted. The massive Sun endows objects or substances on its own surface with twenty-eight times the weight which our Earth can give to similar objects on its own surface. A man weighing eleven stone would weigh about two tons on the surface of the Sun, and while here on the Earth a falling stone falls only 16 feet in the first second, the Sun would draw it to itself at the rate of nearly 470 feet per second.

. . . . .

It is not usual to compare the stars of heaven with earthly candles. But after all, the Sun is, among other things, a stupendous lamp, so that it must be possible to express its brilliance in "candle-power". A good street-lamp shines with a thousand candle-power, while our Sun shines with the light of more than a thousand

quadrillion candles. A thousand quadrillion—that is, a 1 with 27 noughts. It is enough for us to know that this figure *can* be calculated.

"The Sun is a solid body, and is as large as Greece." So said Anaxagoras, and he was a wise man. To-day we are better informed as to its size, and we know that it is essentially a great ball of gas, on whose surface matter can exist only in the form of vapour, on account of the enormous temperature. I say "the surface" with intention. In the interior of the Sun, where the temperature rises to an intensity of many millions of degrees, the conditions are quite peculiar. We shall consider them at some other time.

And now let us examine a photograph of the Sun. It is a circular disc, in which certain spots are visible. The brightness of the surface diminishes perceptibly towards the edges of the disc, so that the image of the Sun has quite a plastic appearance. And this decrease of brilliance towards the edges is a proof that our Sun is assuredly not a solid body, but actually a ball of gas.

In the street, perhaps in an electric sign, and sometimes in well-appointed sitting-rooms, we may see spherical lamps of white opal glass. If we observe such lamps, we shall find that these white globes, although we are perfectly well aware that they are not merely flat discs, none the less have the appearance of plane surfaces, for there is no diminution of luminosity towards the edges of the disc. These spherical lamps are self-luminous solid bodies, and in such luminous bodies the brilliance of the disc is

uniform. If the Sun appeared to us as a disc of uniform brilliance we should have to conclude that it too was a solid body. But it does not appear of uniform brilliance; its luminosity diminishes towards the edges of the disc.

The outer shell of the Sun is relatively colder than the interior, on account of its continual radiation into cold space. Now, the light of the Sun has to force its way through this superficial layer. In the centre of the Sun's disc the path of the light through this layer is shorter than elsewhere, as here the light passes through the absorbent layer at right angles to the surface. Here, then, the brilliance of the rays is relatively least diminished, but near the edge of the disc we have a very different state of affairs. Here the rays of light emerge from the interior of the Sun at an angle to the surface, travelling a comparatively long way through the absorbent layer, so that their brilliance is considerably diminished.

. . . . .

A fairly good telescope enables us to perceive that the surface of the Sun has a peculiar structure. Its appearance has been likened to a thick broth of rice, or to willow-leaves, so that this peculiar structure is described as "granulation"; though a single one of these "grains" is as large as a terrestrial province.

The pattern of the surface is continually altering. From time to time we find small dark "holes" in the brilliant surface. These are known as pores; or if they attain a certain size we call them *sun-spots*. They are

sometimes so large that we can see them even without a telescope, through a piece of smoked glass; or just as the Sun is setting, and the vapours of the horizon take the place of the smoked glass. If we observe the details of the solar disc from day to day, so far as our envious terrestrial clouds will permit us to do so, we find that these spots, which for the most part are arranged in groups, alter their position from day to day, moving slowly across the face of the sun. If a spot appears to-day on the left-hand edge of the disc, it will disappear, about a fortnight hence, round the opposite edge, and in due course, if it does not fill up in the meantime, it will again come into sight on the eastern edge. As a result of our observation of these spots we conclude that the Sun rotates upon its axis.

But the sun-spots do not merely move from East to West. Every observer will be struck by their great alteration in shape. As a rule the centre of the spot is dark, and is surrounded by a border, which is known as the *penumbra*. The sun-spots are vortices, tornadoes of inconceivable violence, in which enormous masses of gas are whirled in rapid movement, and they possess magnetic fields which are sufficiently powerful to produce observable effects on our Earth, over a distance of 93 million miles.

. . . . .

In 1826 an amateur astronomer of Dessau, Schwabe by name, began systematically to study the frequency of the sun-spots. This work was afterwards continued

by the astronomers of Zurich, and Wolfer of Zurich drew more than ten thousand charts of the Sun's disc.

This is work which the amateur astronomer may undertake with satisfactory results. With a small telescope, a notebook, a pencil, and half an hour's work on every sunny day, he can really accomplish something of scientific value. The few observatories which include the recording of sun-spots on their programme are always thankful for the assistance of independent observers.

The science of astronomy now has at its disposal a mass of observations which cover a full century, and individual records have been discovered which go back even to the seventeenth century.

. . . . .

A periodicity is plainly perceptible in the frequency of the sun-spots. Taking an average, they are especially abundant every eleven years, and in the years between these periods their number dwindles to nothing. Scientists have tried to explain this periodicity, and to this very day attempts are being made to discover the reason of this peculiar rhythm. If an earthquake is reported anywhere, you will hear people say that the sun-spots are responsible, and if it rains on a bank holiday people who know that there are such things as sun-spots only from reading of them in the newspapers may declare that they are guilty of spoiling their holiday. But the matter is not so simple as that.

Up to the present it has hardly been possible to

prove that the frequency of the sun-spots has any effect upon the temperature of the Earth. There can be no question of any direct action on the often only subjectively rated contingencies which we call "good" or "bad" weather. On the other hand, it is certainly a fact that the displays of the *aurora borealis*, or "Northern lights", are particularly splendid in years when the sun-spots are especially active.

The terrestrial globe is a spherical magnet. We know where its magnetic poles are situated. In some still mysterious manner the invisible rays from the magnetic fields of the distant sun-spots excite the Earth, so to speak, until it glows about the Poles, and the fluctuations of these magnetic fields are registered by the aurora borealis and australis.

We often hear of magnetic storms, and we know that they are especially prevalent when a large group of sun-spots crosses the central meridian of the Sun's disc. The reports of such disturbances are always correct; at the same time, the word "storm" is liable to give us a somewhat exaggerated idea of the facts.

We know that the magnetic needle points only approximately to the North. The deviation, or *magnetic declination*, must be known if we are to guide ourselves by the compass. In cellars deep underground, which are usually far removed from the disturbing influence of electric mains, the smallest movements of the needle are registered, and if any rather sudden variations are observed, though they are only quite harmless oscillations, we speak of a "magnetic storm". There is no lightning, no thunder; we human beings have no

perception of the disturbance. But it is something very much more than a mere thunderstorm! On the Sun a stupendous whirlwind is raging, compared to which one of our typhoons is child's play.

The distinguished astronomer Hale, at the solar observatory of Pasadena in California, made, not very long ago, an interesting discovery relating to the surface of the Sun. By means of special apparatus he was able to determine, in the case of every solar cyclone, whether it was north magnetic or south magnetic. And he formulated the following law:

The polarity of the sun-spots, in any period of eleven and a half years, is always the same, from minimum to minimum, but in every fresh period there is a complete transformation of the north magnetic fields into south magnetic fields, and vice versa, so that every twenty-three years there is a recurrence of the same conditions. Consequently, we ought to speak of a period of twenty-three years, and not of a period of eleven and a half years.

. . . . .

Strange and amazing are those appearances on the edge of the Sun's disc which we call *prominences*: clouds and garlands of fire, which shoot upwards with mysterious rapidity to a height of more than 200,000 miles, altering their shape in the course of a few minutes; stupendous witnesses of still more stupendous energies. They form themselves out of the solar atmosphere, which surrounds the gaseous sphere of the Sun like a transparent veil. The continuation of this veil

in outer space consists, in all probability, of innumerable discrete particles of "cosmic dust". It forms a nimbus, like a saint's halo, round the body of the Sun. This nimbus, the *corona*, is, of course, visible to us only for a few moments on the very rare occasions of a total eclipse of the Sun, and is one of the most magnificent of all heavenly spectacles.

. . . . .

The corona extends into space so far that its diameter is many times that of the Sun. There is reason to believe that the material of the corona, the "cosmic dust", extends even to the orbit of the Earth—and even beyond it. The *Zodiacal light*, which may be seen, not only in the Tropics, in a perfectly clear and moonless sky, on Spring evenings in the West, and on Autumn mornings in the East (more particularly from the summits of high mountains), in the form of a slanting pyramid of light, should probably be regarded as an extension of the corona.

The Zodiacal light has also been called the "false twilight", but may easily be distinguished from the latter. The peculiar outline of the Zodiacal light is unmistakable, while the twilight fades evenly and perceptibly into the dark heavens.

. . . . .

An eclipse of the Sun occurs only when the Moon, on its wanderings, interposes itself between the Earth and the disc of the Sun. More often than not it covers only a portion of the Sun, and we then see the Sun

as a crescent; such eclipses are partial eclipses, and are familiar to all of us. The great event of a total eclipse occurs only when the position of the observer and the centres of the Sun and the Moon are in a perfectly straight line.

In the year 1842 the poet Adalbert Stifter witnessed a total eclipse of the Sun. Only a poet could adequately describe the impression produced by such a celestial marvel:

. . . . .

"It was strange to think that this mysterious, massive jet-black creeping thing, which was gradually eating up the sun, could be our moon, the beautiful, gentle moon, which at other times illumines our nights like a silver flower; but it was the moon, and through the telescope one could see the indentations and prominences on its rim, the terrible mountains upreared upon the disc that looks at us with such a friendly smile. . . . At last the effect of the eclipse was visible even on the earth, becoming more and more impressive in proportion as the glowing crescent in the heavens diminished. The river no longer sparkled, but was now like a grey ribbon; dull shadows lay about the earth, and the swallows were growing restless; the soft and lovely radiance of the heavens was extinguished as a mirror is dulled by a breath; a little cool breeze arose and blew against us; the light on the meadows was indescribably strange, grey and heavy as lead; in the woods no movement was visible, now that the play of light had ceased, and they lay at rest;

a rest which was that not of sleep, but of unconsciousness. Duller and duller the shadow flowed over the landscape, and all things grew more and more motionless. Our shadows lay empty and unsubstantial along the walls; our faces turned ashen grey; and this gradual dying, in the midst of the morning freshness which had prevailed but a few minutes earlier, was deeply impressive. We had imagined the onset of darkness as resembling the evening twilight, though without the red of evening; yet how spectral the coming of night could be without the flush of sunset was something we had not imagined. But apart from this, the twilight that was now falling was quite different from that of evening; it was oppressive, a mysterious estrangement of familiar Nature. Towards the south-east was a strange reddish-yellow gloom, and the mountains were dyed with it. The town at our feet sank deeper and deeper, as in an illusive shadow-show; and the people walking or driving across the bridge were as though we saw them in a black mirror. The tension reached its climax. I took one more glance through the telescope—it was the last; now the glowing crescent was as fine as though scratched on the darkness by the point of a penknife; at any moment it might be extinguished, and as I raised my eyes from the telescope I saw that all the others had put aside their dark glasses, and were gazing upwards with their naked eyes. They needed no protection now, for on high the last spark of the sun was dying like the last spark of a smouldering wick; gleaming, perhaps, through the ravine between two mountains of the

moon. It was a most melancholy moment. Now disc stood covering disc—and this moment it was that really wrung the heart. No one had imagined what it would be like; there was a general 'Ah!' from all throats, and then a deathly silence; this was the moment when God spoke and man hearkened."

. . . . .

One very remarkable phenomenon has often been described as occurring at the last moment before totality: the so-called "flying shadows", which rush away over the ground and the walls of the adjacent buildings like a series of scampering waves. Kostersitz discovered that the same phenomenon may be observed on a wall when a search-light is casting its rays just over the roofs of a town, and concluded that in both cases the cause of the curious appearance is the same. The luminous point of the arc lamp in the search-light corresponds to the last dazzling point of the disappearing disc of the Sun, shining through some indentation of the edge of the lunar disc (which is not, of course, quite even), and in both cases the varying refractive power of the air, due to rising currents and eddies, must be responsible for these peculiar projections.

. . . . .

The solar prominences consist substantially of metallic vapours and incandescent hydrogen. We find that many of our terrestrial elements are represented in the Sun, and we are convinced that the chemistry of the

Sun's surface and the chemistry of the Earth are one and the same.

But how is it possible to determine the constituents of an incandescent mass at such a distance from the Earth?—The art of celestial research which enables us to determine the constituents not only of the Sun, but of the most distant stars, is known as *spectroscopy*.

When a ray of light of any kind passes through a glass prism, what appears to be a point of white light is resolved, if received upon a screen, as a *spectrum*. That is, it appears as a band of the colours of the rainbow; at the same time, this band is crossed by dark lines and streaks, the so-called Fraunhofer lines. These, as it were, divide the individual shades of the many-hued spectrum from their neighbours, or, in the form of wide "bands", eclipse certain tones altogether. Again, it may happen that on an otherwise dark background, in which the tender colours of the rainbow-band can hardly be recognized, certain luminous lines appear.

We may observe the same phenomena as those produced by a prism or combination of prisms if we allow light to pass through a plate of glass on which are engraved many thousands of lines to the inch. Such a plate is known as a *diffraction grating*. *Spectro-analysis* is the science which enables us to deduce, from their spectra, the substances, and the condition of the substances, of which a luminous body consists. The founders of the science of spectro-analysis were the chemist Bunsen and the physicist Kirchhoff,

both of whom were working in Heidelberg about 1860.

. . . . .

Spectroscopy teaches us two things:

1. To every element belong certain definite lines in the spectrum, which occur always in exactly the same positions, and in precisely the same order. If the lines of such an element appear in the spectrum as *bright* lines, then we know for certain that the chemical element in question exists in the source of light under investigation in the form of incandescent vapour.

2. If these lines appear dark, while the background of the spectrum shows its rainbow colours—as happens, for example, in the spectrum of the surface of the Sun—this indicates, as laboratory experiments have proved, that a luminous body is transmitting its rays through the vapour of this element; which, if it were shining alone, would give us precisely the same lines, but they would then be bright on a dark background.

Moreover, the measurement of the spectrum gives us information of movements on the Sun's surface, and even of the movements of the stars.

. . . . .

Imagine a machine-gun mounted on a motor-car. Suppose the weapon to be so constructed that its bullets strike a distant target at intervals of precisely one second. And now, while the bullets are flying, the car rushes towards the target. The bullets will strike the target in more rapid sequence. And now, while

the gun is still bombarding the target with its projectiles, the car travels away from it. The frequency of the impacts is diminished. The interval between them is now more than a second.

And now, in the place of the target, imagine the retina of the eye, and in place of the stream of bullets the rapidly alternating impulses—400 to 800 billions of oscillations per second—with which the waves of light beat upon our eyes. And now let us imagine the following state of affairs (remembering that the quantities given are not even approximately such as would occur in nature):

Let us think of a yellow star, a star of such a pure yellow that it emits *only* yellow rays, so that its spectrum shows no other shade or colour beyond the yellow region. Such light—light of only one colour—is known as monochromatic. Yellow light makes 550 billion oscillations per second.

Now let this star approach us—that is, let it approach our eyes—at an unthinkable speed: just as, in our comparison, the machine-gun approached the target. Instead of the 550 billion oscillations we shall now receive a larger number—we shall receive 600 billion every second. But these 600 billion oscillations per second evoke in our eyes a sensation of *green*.

Thus the yellow star has become green. In the same way, the bright yellow of the star would become orange if it were to move away from us with like rapidity, since orange light makes fewer oscillations per second than yellow. Now, as a matter of fact the differences observed are never so great as these. A

yellow star remains yellow, and a red star red; but we can, for example, in the spectrum of the left-hand edge of the Sun, which is moving towards us on account of the Sun's rotation, perceive that the black Fraunhofer lines, which in this case, of course, occur in the place of bright coloured lines, are displaced towards the violet end of the solar spectrum, while on the opposite edge of the Sun the lines are displaced in the same degree towards the red end.

By observations of the spectrum, therefore, it is possible to determine the movements even of distant stars. The method employed, which is astonishingly accurate, is the application of what is known as *Doppler's principle.*

CHAPTER III

AN EXCURSION TO THE MOON

LET us go out into the moonlight.

It is a summer night, and the Moon is at the full; the round golden disc is shining low in the south-east. It has a face, a real face, with eyes, and a nose, and a mouth. The darker patches on its surface make it easier for us to imagine that there is life on the Moon. But in reality the Moon is dead. No animals, no plants exist on its surface, for the necessary air and water are lacking. If we speak of the inhabitants of the Moon, we call them "Selenites"; but they are only the children of our fancy.

The dark patches on the bright disc are known as "seas". People used to think that the Moon and the Earth were alike in all essentials, and that there must therefore be large expanses of water on the Moon. We have retained the names of the seas, although we now know that the surface of the Moon is dry. We can see on the Moon, even on the crescent of the new moon, a Mare Crisium, "a sea of crises"; and there is a "sea of nectar", a "sea of fruitfulness", a "sea of quietness", and an "unruffled sea". When the Moon has passed its first quarter yet other seas, and even oceans, make their appearance; their names signify "rain", "mist", "moisture", and "storm". It was at one time quite usual to forecast the weather in accordance with the phases of the Moon. We have now realized that the changes of the weather are by no means so simple to

foretell as the changes of the Moon, but we have retained the old names of the so-called seas.

The lunar seas are really wide plains, and through the telescope we see that beside these plains there are many so-called craters on the Moon—ring-shaped mountains, and regular mountain-ranges.

. . . . .

The Moon travels round the earth in approximately twenty-seven days. If to-day it is near the star Regulus in the Lion, it will run through the twelve constellations of the Zodiac at just such a rate that about twenty-seven days later it will once more be passing Regulus. This period—reckoned from a star to the same star—is called the "sidereal period", from the word *sidus*, a star. Now in this period of twenty-seven days the Sun has altered his position among the stars, moving in the same direction as the Moon. Consequently, supposing that the Moon is now level with the Sun, it will take *more* than twenty-seven days to pass round the heavens and overtake the Sun again. Such a period, "relative to the Sun", or the time between new moon and new moon, is twenty-nine and a half days in length; and this we call a "synodic period", or a "lunation". Within this period the Moon displays its different "phases".

The Moon is smaller than the Earth; if it "fell down" it could comfortably find room in half the Sahara. Roughly, its diameter is one-fourth the diameter of the Earth. A quadrant of the Earth, from the North Pole to the Equator, measures 10,000 kilo-

metres. If the diameter of a sphere is one-fourth the diameter of another sphere, then the circumferences stand in a like relation. The circumference of the Earth is 40,000 kilometres; the circumference of the Moon is therefore 10,000 kilometres—approximately, since the diameter of the Moon is only approximately one-fourth that of the Earth. Now we know how many days we should have to travel, supposing we could reach the Moon, in order to take a "voyage round the Moon". From the top of the head, across the ear and chin, and back to the top of the head again would take ten days in a fairly rapid railway-train. We may bear in mind that a day's journey on the Moon would cover about one-tenth of the circumference of its disc, and with this day's journey for comparison we shall be in a position to estimate the width of the lunar seas. We shall readily understand, for example, that even the little dark patch high up on the right, on the temple of the face, the Mare Crisium, would almost fill the space between London and Edinburgh. It looks elliptical, but this is due to perspective distortion. We are looking at it sideways; in reality it is circular. (Fig. 9.)

. . . . .

We shall need no rockets, no technical preparations for our journey to the Moon. Astronomers, if we are to believe them (and whom are we to believe, if not the astronomers?) have been there before us, and have told us all about it.

Kepler, in his *Dream of the Moon* (and a dream-journey is the quickest way of reaching our satellite),

relates how the Icelandic witch Fiolxhilde tells her son Duracoto how nine spirits, who hate mankind and the light of day, travelled to the Earth from Levania—that is, the Moon—in the shadow of an eclipse. The purest and gentlest of them is adjured by an incantation of twenty-one letters, and this "demon from Levania" favours us with a regular system of astronomy, as understood by the Selenites.

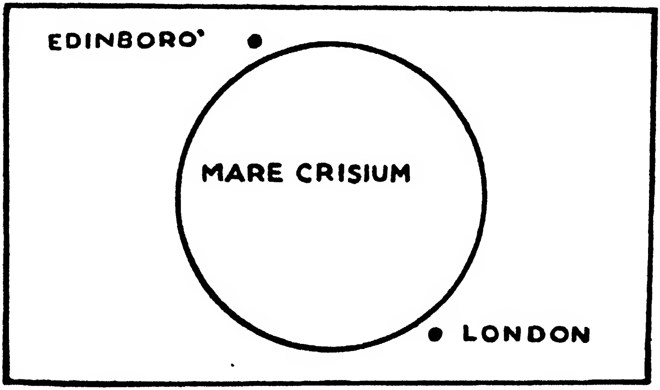

FIG. 9.—The Size of a large Lunar Crater.

"There is no air on the Moon; no atmosphere, brilliantly illumined by the Sun, and prevailingly blue in colour, to outshine the light of the stars. We see the many thousand lights of heaven by day as well as by night, even though the Sun may be shining in the midst of them. The Sun is a white disc with a sharply defined edge, no larger in diameter than when we see it from the Earth, but it rises and sets so slowly that a day with us is equal to a whole earthly month. The

Milky Way, which on Earth is often hidden by clouds of vapour, is a ribbon of metallic lustre."

To us dwellers on the Earth the Moon shows always the same face. It moves like a child who holds both our hands and dances round us in a circle. The child is actually revolving, but in such a way that his laughing face is always looking up at us. In the same way, we see always the same face of the Moon, the same seas and mountains; even as its phases alter it never turns its familiar face away from us. It follows, then, that the Selenites perceive our Earth always at the same point of the heavens, rotating, with all its seas and continents, about its axis.

Nevertheless, to us dwellers on the Earth the face of the Moon does not appear quite motionless. "The man in the Moon nods his head to us so that now we see a little more of the top of his head, and now a little more of his chin. Then he lazily shakes his head, so that one can see a little way behind his ears." The scientists call these oscillations "librations", and in the course of weeks and months we see, on account of these librations, not only one-half, but about seven-twelfths of the entire surface of the Moon.

The Selenites feel this libration as little as we Earth-dwellers feel the movement of the Earth. The ground is still beneath their feet; yet they can see that the Earth, as it spins in the sky, changes its place amidst the stars by a few degrees, moving now in this direction, now in that. To the dwellers in the Moon the Earth appears enormous—almost four times as broad as the Moon appears to us. The causes of the librations are

complex; but some of them are explained by the fact that the orbit of the Moon, like the orbit of the Earth, is not a circle but an ellipse.

. . . . .

How long is the journey to the Moon?—Here are our surveying instruments: a walking-stick and two ordinary pins. These will tell us all we want to know. Sixty centimetres from the tip of the walking-stick, which we hold up to one eye, we make a little notch. Into this notch we thrust our two pins, parallel to one another, and precisely half a centimetre apart, and we look at the Moon between the pins, as though through a telescope. The disc of the full Moon will be just included between the two pins. Now let us imagine that the half-centimetre gap between the two pins is replaced by a pea; we should then find by experiment that the pea just covers the full Moon when it is held 60 centimetres from the eye. That is, when it is 120 times farther from the eye than its own diameter.

Now let us make—or imagine—a little diagram. From a point E—to represent the eye—we draw two long divergent lines, with a small angle between them, and we place two circles in the space between the lines: one, representing the pea, near the eye, and the other, farther away from the eye, the Moon. It will now be obvious, if we consider the relative sizes and positions of the two circles, that if the pea is 120 times farther from the eye than its own diameter, our Moon likewise must be 120 times farther from us than *its* diameter.

We have solved our problem. The distance between the Earth and the Moon is 120 moon-diameters, or roughly, 30 times the diameter of the Earth. The Moon is only 60 times farther than America. When a ship's captain has crossed the Atlantic, and returned, 30 times, he has covered a distance that would have taken him to the Moon.

. . . . .

"Fifty-thousand miles away in space," said Kepler's demon, "lies the island of Levania. The way from the island to the Earth and back is very seldom open; for the Earth-born it is very difficult, and attended with great danger to life. We take no persons of sedentary nature as our companions, no corpulent persons or voluptuaries, but only such as spend their lives hunting on horse-back, or such as have frequently sailed to the Indies, and are accustomed to nourish themselves on biscuits, garlic, and dried fish, and other foods despised of gluttons. Especially fitted to be our companions are emaciated women, who have in all ages known the secret of making swift and endless journeys about the earth, riding by night upon he-goats, broomsticks, or tattered mantles."

The distance to the Moon is about 240,000 miles. After thousands of years of civilization we have progressed so far that we can raise ourselves from the Earth to a height of some 6 miles, if conditions are good, and a record is at stake. If we could fly about 38,000 times higher we should be able to reach the Moon, and make the acquaintance of its inhabitants.

There was as a matter of fact a time—and of much more recent date than the days of Herschel, who imagined a Paradise in the Sun—when it did not seem entirely unreasonable to believe in the existence of "men in the Moon", for according to the calculations of a really eminent astronomer there might have been life on the Moon.

It was ascertained that the Moon was not a perfect sphere, and it was calculated that the farther side was slightly depressed. The landscape of the visible half of the Moon, the half which faces the Earth, and which consists of elevated plains and mountains, has long been barren of all life, if any ever existed there. Yet—it was argued—it is not unthinkable that all the water and air may in the course of time have flowed on to the farther side of the Moon, and that there, in the "depressed" regions, they might support not only a vegetation, but living creatures: there animals, and even human beings, might be evolved.—The Selenites would have their own civilization, and might very well be infinitely happier than we are. But we should never be able to catch even a glimpse of them, since it is quite impossible that we should ever be able to look round the edge of the Moon.—But why should not the Selenites oblige us by venturing out of their paradisal "depression" and emerging on to the side of the Moon that is turned toward the Earth, so that we could see them through our giant telescopes? Well, their inhabited regions are surrounded by impassable deserts like those we see through the telescope.

And yet some daring Selenite, some desert explorer,

may at some time have peered over the "rim" of the Moon, and may have seen, through his telescope, signs of the human race?—No, it is quite impossible. I am sorry to have to say it—but in calculating the shape of the Moon the astronomer made a slight error. The "depression" at the back of the Moon does not exist. And so, alas, there are no Selenites.

. . . . .

The Moon is perhaps the most refractory object in all the celestial mechanism. There are lunar formulæ of two hundred lines; it takes whole pages to write a single formula! Of such calculations I shall, of course, say nothing. But one must master these terrible formulæ if one wishes to gain an insight into the mysteries of the Moon's movements. And when the famous enlarged photographs of the Moon were made in Paris, the clockwork mechanism which enabled the telescope and camera to follow the Moon had to be complicated by all sorts of ingenious gearing before it could deal with the complex aberrations of our satellite.

It sounds a curious thing to say, but it is perfectly true: the reason why it is so difficult to calculate the movements of the Moon is—because the Moon is so near the Earth. It is nearly a quarter of a million miles away—but it is 400 times nearer than the Sun, and many million times nearer than Sirius.

Suppose we are standing on a hill; across the plain beneath us, a long way off, a motor-car is travelling. You will agree that an engineer, by taking different measurements at different moments, could calculate

the direction and the speed of the motor-car with the utmost accuracy.—But now a bee comes buzzing past our noses. Who can observe and calculate its precise trajectory? It would be a hopeless undertaking; the little bee is *too near.*

. . . . .

In Vienna they call an opera-glass a *Zuwizahrer*: a colloquial expression which may be translated as "a bring-'em-nearer"; it means, of course, that such an instrument brings the stage nearer to us. The opera-glass, strictly speaking, is a pair of Galilean telescopes, and, like the astronomical telescope invented by Kepler, it brings the stage of the heavens nearer to us. With a magnification of 60 diameters the Moon appears sixty times nearer, and since its distance from us is just sixty times that of the middle States of America, it looks, under such a magnification, as it would if it were seen across the Atlantic. A magnification of 600 diameters brings the Moon to within 360 miles of us, and with a magnification of 4,000 we should be able to study the mountains of the Moon as closely as we can study the mountains of Earth at a distance of 60 miles with the naked eye. That has a fascinating sound; but there is, unfortunately, one difficulty that no telescope can overcome. If we increase the magnification beyond a certain point the details are, of course, enormously magnified, but they are dim and blurred and unsteady, so that we are soon obliged to go back to a more modest magnification. Especially when the atmosphere is at all

disturbed, the slight distortions due to the varying density of the air-currents are enormously magnified, and the image of the Moon is blurred beyond recognition.

. . . . .

How is a telescope constructed?—It is a wonderful instrument, despite its defects. Like all human achievements, it has its limitations; but for all that it is a wonderful instrument.

In order to understand the construction of the telescope, let us consider the photographic camera. The very simplest photographic apparatus is an ordinary cardboard box, with lid. With a pin, or a red-hot needle, a hole is made in one of the sides of the box, through which the rays of light from without may enter its dark interior. If we slightly raise the lid and peep into the box, covering our head with a wrap as the photographer does with his focusing-cloth, so that no light can enter the box except through the hole which we have made, and if we point this hole towards the brightly lighted landscape, we shall see, on the side of the box opposite the hole, a perfect, many-coloured picture of the landscape, dimly lighted, perhaps, but perfectly sharp in outline. If the "aperture of the camera", as we will call the pin-hole, is pointed in the right direction, we may even see people walking about in the projected image of the landscape, though they will, of course, be head downwards. If we allow this image to fall on a sheet of sensitized paper we can even take a photograph with this camera.

With such a "pin-hole camera" amateur astronomers have taken quite excellent photographs of the solar crescent during eclipses. The Moon, of course, even when at the full, emits too dim a light for our humble camera. To photograph the Moon we should have to make the aperture a good deal larger, and if we did that the picture in the box would be blurred, if not quite unrecognizable. The problem of increasing the brilliance of the image without diminishing its sharpness is solved by employing a lens. The lens, despite a very much greater aperture, will transmit every ray of light from the object before the camera in such a direction that the image produced will correspond exactly to the object and be sharply defined. Such a lens or (as is more frequently the case) combination of lenses, when employed to throw an image in the camera, is known as an *objective*, because it is pointed at the object. If this is so far from our camera that it does not matter whether it is a yard or two nearer or farther, we say that the lens (when in such a position as to give a clear image of the object) is "focused on infinity"; but this, of course, is only "a manner of speaking".

If an object is so far distant from the camera, then the back wall of the camera must be in a perfectly definite position as regards the lens, and the distance between the lens and the wall of the camera on which the image of the distant object falls is known as the "focal distance" of the lens. If we were incautiously to throw an image of the "infinitely" distant Sun on to a sheet of paper, it would burn a hole in the paper;

hence the expression "focal" (from the Latin *focus*, a fire-place). The lens might be likened to a funnel; the larger its opening, the more light and heat it is able to gather and concentrate.

The camera is easily understood. But now we will make a further experiment. So far we have only a lens and a box; now we will replace the back of the box by a sheet of ground glass, a so-called "focusing-screen". Looking at the glass in the direction of the object, we see on its translucent surface an image of the object. In order to examine it more closely we will take a magnifying-glass.

The picture is now so large and clear that we are able, although it is upside down, to distinguish the finer details of the distant landscape. And now, here is a little surprise for you. Without moving the magnifying-glass, we slip the ground glass aside, and now, on looking through the magnifying-glass, we find that the image is still visible, just as it was before, except that it is much clearer. Now we have an actual telescope; and now we understand the significance of its component parts.

The *objective* produces an image not only on the ground glass focusing-screen, but, when this is removed, "in the air", and this otherwise invisible picture is merely enlarged by the magnifying-glass, or *eyepiece*. No eyepiece, however efficient, will show us anything that is not presented to it by the objective. If the image produced by the objective is not quite faultless, magnification by the eyepiece will give us only vague, blurred shapes. Both objective and eyepiece must co-operate in

order to produce a perfect picture. The focal length of the objective, divided by the focal length of the eye-piece, gives us the magnifying power of the telescope. It will be understood, of course, that it is not the object itself which is magnified so many times or diameters, but only its angular width when seen with the naked eye.

. . . . .

Hitherto we have spoken only of telescopes which have lenses for objectives, or *refracting* telescopes, as they are called, though this description is, as a rule, applied only to telescopes of a certain size. Besides these, there are *reflecting* telescopes. In these the image is projected not by a lens, but by a concave mirror. The largest refracting telescope in existence to-day is that of the Yerkes Observatory in Chicago. The great objective measures 40 inches in diameter. The largest reflector—100 inches in diameter—is in the Mount Wilson Observatory, near Pasadena, in California; but in Paris plans have been made for an even larger instrument.

. . . . .

Let me tell you—just to amuse you—what some enterprising people in America proposed to do some years ago. They wanted to observe, not the Moon, but our remoter neighbour, Mars; and they wanted to get a really good view of the planet. They were going to achieve a record in the way of telescopes.

I am sometimes reminded of their wonderful scheme when I stir my morning coffee. You know that when

we stir our coffee to dissolve the sugar the rotating surface of the coffee becomes concave, as the surface of any liquid will do when it is made to rotate; it is almost like the reflector of an automobile headlight, and if only it would reflect enough light it might even project a wavering image, like the reflector or speculum of a telescope.

Well, instead of a modest coffee-cup these ingenious people were going to make a gigantic circular pot or pan, 50 feet in diameter. This pan was to be filled with quicksilver. It was to be rotated by electric motors, and the concave surface of the quicksilver, which would act as the reflector of a huge reflecting telescope, would produce an image of Mars which would enable the observers to discover the most interesting details of the Martian landscape, and possibly even the inhabitants of the planet! Well, I need not particularize the innumerable defects which would make such an instrument impracticable.—I forget whether I read of the project in the newspapers, or learned of it in the cinema. Perhaps the idea originated in Hollywood!

. . . . .

To-night the Moon is at the full. Ten days ago—it was a beautiful sight—Venus, the "evening star", shone close beside the crescent of the young Moon, and one could see not only the bright portion of the Moon, but all the rest of its surface, though it was only very faintly illuminated. How is it that we are sometimes able to see "the old Moon in the new Moon's arms"?—

Part of the Moon's surface is lighted by the Sun; this shines with a very bright light. But the beams of the sun fall not only on the Moon; they are shining on our Earth as well, though now, after sunset, they are lighting only those regions of the Earth that lie to the west of us: the Atlantic Ocean, and America. And this part of the Earth, like a great mirror, reflects the sunlight back into space, and lights up that part of the Moon which is in shadow as regards the direct rays of the Sun. The grey light of "the old Moon in the new Moon's arms" is therefore "earth-light"; but this light is often so powerful that with a telescope one can study the details of the Moon's surface in the shadowed region.

The best times for the telescopic observation of the Moon are the days of its first and last quarters. At these times we get a particularly good view of those regions of the Moon's surface which lie near the "terminator", as we call the bounding line between light and darkness. Here the irregularities of the surface cast long pitch-black shadows, and the "moonscape" is enlivened by the most brilliant contrast of light and shade. We shall see no such contrast to-day, now that the Sun and the Moon are, so to speak, facing one another; for at full Moon the observer has the Sun at his back; and we know that no photographer would photograph a group of people with the Sun directly behind him; the resulting picture would be lacking in contrast.

The lunar "seas" are not particularly interesting, even when seen through the telescope; but the moun-

tains offer a fine spectacle. It is possible to ascertain their height from the length of their shadows. They are of much the same height as our own mountains, and they have even been named after terrestrial peaks and ranges. For example, there are "Alps" on the Moon, and a "Valley of the Alps", though this hardly has its counterpart anywhere on our Earth. It looks as though a gigantic meteor, a huge heavenly body, had come rushing out of space and had just grazed the Moon, leaving an enormous scar. Other ranges of mountains are the "Apennines" and the "Carpathians", and we even find a "Caucasus" on the Moon.

By far the most interesting formations on the Moon are the so-called "craters"—great circular walls, which are seen in great profusion. The Mare Crisium is really nothing more than a gigantic crater.

It was not unnatural that the first observers should have called these formations craters. At a cursory glance they are not unlike the craters of our terrestrial volcanoes. But on closer examination we find that the comparison is inexact. The smallest craters are from half a mile to five or six miles in diameter; the crater called Copernicus is over 50 miles in diameter, Plato about 60 miles, and Ptolemy 110. Let us imagine ourselves in the centre of one of these vast craters. We should probably find that we were surrounded by a level plain, enclosed by distant mountains, which, as regards its contours, would not be very different from any terrestrial plain. It would never occur to us to

compare such an enclosed plain with the gullet of one of our volcanoes.

. . . . .

In view of their enormous dimensions, then, it seems that we are not justified in concluding that the origin of the circular formations on the surface of the Moon is similar to that of our volcanoes. Some astronomers have accordingly suggested that the walls of the craters are the relics of enormous bubbles, which were formed when the surface of the Moon was congealing; but in view of the colossal size of many of the craters this theory can hardly be seriously considered.

But another attempt to explain the origin of the craters has found many supporters. It is suggested that they were caused by the fall of great numbers of meteorites, of great masses of stone or metal, wandering through space. Before the crust of the intensely hot Moon (the interior of which is still, in all probability, extremely hot) was able to offer much resistance, any heavy mass falling upon it would penetrate through the surface. Experiments have been made in which bullets or marbles were allowed to fall into a mass of soft plaster of Paris, and the resulting formations did, as a matter of fact, resemble the craters of the Moon. Very often these experiments resulted in the formation of little prominences in the middle of the hollows, just as we often see them in the craters of the Moon. The following objection to the meteoric hypothesis has often been made: If it is true that enormous masses of meteoric material did at one time follow orbits which

brought them into the neighbourhood of the Moon, how is it that our Earth does not show innumerable scars of their impact, like the craters of the Moon? If swarms of meteors were passing in the immediate neighbourhood of the Moon, the Earth, being comparatively near them, would certainly not escape them, and since the surface of the Earth is and always was considerably larger than that of the Moon, the Earth ought to show a proportionately greater number of scars than the Moon.—To this objection we can make the following reply: the Moon and the Earth are bodies of very different dimensions. It is to be assumed, since they were formed of material drawn from the Sun, as we shall presently describe, that the Moon would already have possessed a comparatively cool and hard, though still thin crust, while the much more massive Earth, which constituted, so to speak, a much greater reservoir of heat, was still a hot, soft ball. A meteor that fell upon the surface of the Moon would therefore leave the trace of its impact upon the half-congealed mass of the satellite, while an equally massive meteor would plunge, without leaving a trace, into the seething, molten mass of the Earth.

But the meteoric hypothesis has one weak point. We will assume that it was at one time possible that heavenly bodies of such a size may have plunged into the Moon that craters of even 60 miles in diameter may have resulted. But how are we to explain the fact that all these craters, without exception, are perfectly circular? For even the elliptical craters on the edge of the Moon are, as we have seen, really circular, being

merely distorted by the effect of perspective. But we should naturally expect that the meteors which plunged into the Moon would strike it at all kinds of angles. In this case, however, they would have left not only circular traces, but also long elliptical scars, and even straight furrows, like the "Valley of the Alps", must have been of frequent occurrence. Nevertheless, there is on the Moon only one Valley of the Alps. It seems, therefore, that the meteoric hypothesis is untenable, despite all the attempts that have been made to uphold it.

Of the many other hypotheses I can here mention only one. To understand this we must, in imagination, go back to the time when the Earth and the Moon still constituted a single body. The "Earth-Moon" was once upon a time a single rotating mass. Under the action of centrifugal force, which acts from the centre outwards, this mass assumed the shape of a pear. Near the smaller end the pear became gradually constricted, until at last the two severed portions—one large and one small—were circling round one another. The smaller mass was the Moon, and the older cosmogonists assume that in the earlier stages of its evolution it rotated about its axis much more rapidly than it does to-day, when the period of one revolution is precisely equal to the time it takes to complete its orbit round the Earth. In order to understand how the craters may have come into existence, let us imagine that the surface of the Moon—which is still rotating far more rapidly than at present—has not yet become a firm and impregnable crust. There are still many

places where it is incapable of resisting great pressure, whether from within or from without.

Now, it goes without saying that the whole mass of the Moon is subjected to the attractive force of the mass of the neighbouring Earth. The crust, considered by itself, will hardly be affected by this force of attraction, but it will be quite otherwise with the incandescent magma in the interior of the Moon. In those parts of the Moon which are nearest to the Earth it will be drawn up so strongly against the outer crust that the softer or thinner places will give way, allowing the magma to flow up through the breaches. Since the lava will flow at the same rate in all directions, it will inundate circular areas wherever there are flaws in the Moon's armour. It is now high tide in the region of the future "crater".

But the Moon is turning on its axis. Presently the flooded region has reached such a position, in relation to the Earth, that the "tide" begins to ebb. The lava flows back into the breach. Another half-revolution, and it is once more high tide; another, and the tide has ebbed again; and so it continues; and every time the tide recedes some of the lava congeals at the circumference of the inundated area, until a circular wall is built up. There we have the wall of the crater. The breach in the crust is blocked in the course of time, and it may even happen that a mountain-peak is reared above it, testifying, as it were, to the last attempt of the lava to inundate the central region of the crater. If, in a later stage of the Moon's evolution, the wound were to break open again, a second wall,

and even a third, might be built up within the first great wall, concentric with the latter; and this, perhaps, may be the explanation of the doubled and trebled craters which we see on the Moon.—

But in spite of all the attempts which have been made to solve it, the problem of the lunar craters remains to this day as great a riddle as the problem of the nature of the rock which forms the mountains, and indeed the whole surface, of the Moon. Attempts have been made to ascertain the nature of this material from the so-called *albedo* of the Moon's surface—that is, its capacity for reflecting light and heat, which can, of course, be measured. Only this much is certain, however: that the rock has about the same capacity for reflecting rays as sandstone. We have got no farther than guessing. It may be, however, that some hitherto unsuspected method of physical research will sooner or later give us a satisfactory answer.

. . . . .

Among the remarkable features of the lunar landscape are the so-called *rills*, among which are lines—both straight and crooked—which look as though engraved on the surface of the Moon. They have the appearance of cracks in the surface, though now and then they rise above it. Equally mysterious are the systems of bright *streaks* or *rays* which surround the larger craters, and are very conspicuous in the case of Tycho Brahe and Copernicus. These bright streaks run outwards from the crater, radiating from it like the spokes of a wheel, and are most conspicuous at full moon. They

run their course without taking account of heights and depressions; it is as though the surface of the Moon had been streaked with whitewash.

I cannot here enumerate all those details which make the Moon the favourite object of the amateur astronomer who has the luck to possess even the most modest telescope. Schmidt, in Athens, has drawn a chart of the Moon which contains no less than 33,000 details. The observer will find in the Moon an inexhaustible wealth of objects for observation. Moreover, owing to the librations of the Moon the lunar landscapes alter their perspective relations to one another and to the "rim" of the Moon; while the ever-changing illumination of the surface makes it all but impossible that one should ever see precisely the same picture twice.

. . . . .

The Moon, like the Sun, travels through the signs of the Zodiac, but it does not follow precisely the same track as the Sun. In the course of one revolution round the Earth it is at one point 5° above the ecliptic, and at one point 5° below it, and it crosses the ecliptic twice. This happens because the plane in which it revolves round the Earth does not coincide with the plane of the Earth's orbit round the Sun.

We will try to elucidate this phenomenon by means of our "one-milliardth scale", in which, as you will remember, each 1,000 kilometres is reduced to a mere millimetre.

The Sun, as before, will be represented by a sphere of 139 centimetres in diameter. At a distance of

150 metres a ball the size of a hazel-nut circles round it. Round this Earth revolves a Moon, 3½ millimetres in diameter, at a distance of 38 centimetres. It takes the Earth one year to complete one revolution round the Sun, and in that year the Moon revolves rather more than twelve times round the Earth.

We will assume that this model Earth, as it moves in its orbit round the Sun, is hanging in the air, just in front of us, on a level with this table-top; so that the plane of the table-top, if extended indefinitely in all directions, will represent the plane of the ecliptic, the plane of the Earth's orbit. We must then imagine that this plane, if produced "to infinity", will bisect the heavens along the line of the Zodiac.

Now, if the orbit of the Moon lay in the plane of the table-top, an observer on the Earth would see both the Sun and the Moon exactly on the line of the Zodiac. But this is not the case. The plane of the Moon's orbit makes an angle of 5° with the plane of the ecliptic—that is, with the plane of the Earth's orbit, the plane of the table-top. At the same time, the plane of the Moon's orbit remains always approximately parallel to itself.

We call the line along which the plane of the Moon's orbit cuts through the ecliptic—or the plane of the table-top—the *nodal line* of the Moon's orbit. This line also remains approximately parallel to itself as the Earth carries the Moon and its orbit round the Sun. Consequently it must happen twice a year that the nodal line points directly at the Sun. If it so chances

that the Moon, at these moments, is between the Earth and the Sun, it cuts off the light of the Sun, and we have a solar eclipse. If, on the other hand, the Moon and the Sun are on opposite sides of the Earth, we have an eclipse of the Moon, as the Moon will then pass through the shadow of the Earth. If the Sun, Moon and Earth are not absolutely in a straight line, we have a partial eclipse of the Sun or Moon.

. . . . .

The Viennese physician and astronomer Theodor von Oppolzer undertook, with the help of his assistants, to calculate the date of no fewer than 8,000 eclipses of the Sun and 5,200 of the Moon. His calculations, in the preparation of which no less than two hundred and forty-three thick volumes of manuscript were filled, are published in the celebrated *Canon of Eclipses* (Vienna, 1887). This contains, amongst other things, a tabulated list of all the eclipses of the Sun from 1207 B.C. to A.D. 2161, with all the necessary data for verifying the calculations, and maps of different parts of the Earth's surface, showing the path of the Moon's shadow—that is, the track along which the eclipse will be total—in the case of each eclipse.

. . . . .

In order to calculate eclipses in this manner a very special knowledge of mathematics is required. I do not propose to give you a course of lessons in mathematics, but I will give you a recipe which will enable

even the humblest amateur astronomer to foretell eclipses for himself.

. . . . .

In order to discover what eclipses will occur in a given year—say, in the coming year—we have only to turn to a calendar whose date is 18 years earlier than the year in question. In accordance with a law which was known to the ancient Babylonians, eclipses of a given kind and intensity recur after 18 years and 10 days. This 18-year cycle is known as the "Saros period". If we find that certain eclipses occurred in a certain year, we know for certain that similar eclipses will occur 18 years later; to obtain the exact dates, we have only to add 10 days to the dates of the various eclipses. The following table enables us to verify this period in respect of the years 1906 and 1924:

	1906	1924
1. Total eclipse of Moon	February 9th	February 20th
2. Partial eclipse of Sun	February 23rd	March 5th
3. Partial eclipse of Sun	July 21st	July 31st
4. Total eclipse of Moon	August 4th	August 14th
5. Partial eclipse of Sun	August 20th	August 29th

The period of 18 years and 10 days holds good in each case, with a maximum error of one day.

The Saros period of 18 years is explained by the fact that the nodal line of the Moon's orbit—the line along which the plane of the Moon's orbit cuts through

the plane of the ecliptic—although it does, as we have said, remain parallel to itself if comparatively brief periods of time are considered, actually rotates, very slowly, in the plane of the ecliptic, making one complete revolution in 18 years. Owing to this revolution of the nodes, eclipses occur, during the course of the year, in different parts of the Zodiacal belt.

. . . . .

I must not conclude this talk about the Moon without making a little confession. Some of you may have thought that our method of measuring the distance of the Moon by means of a walking-stick and a pea was just a little too simple to be true. Well, the reason why it was so easy was that we made a hypothesis which we did not verify. We postulated that the diameter of the Moon was about one-fourth the diameter of the Earth. And so, as a matter of fact, it is; but how do we know this? We cannot ascertain the diameter of a heavenly body until we know its distance from us. The problem of measuring distances in space was not solved by means of our walking-stick; so we will give it our attention now.

. . . . .

Let us suppose that we wish to measure the height of a church tower. We mark on the ground a straight base-line, which runs through the middle of the floor of the tower, and extends, we will say, 36 yards in each direction from the central line of the tower. Now, from the ends of this base-line of 72 yards, we

observe the top of the tower, and in each case we find that the angular height of the tower is (we will say) 70°. What is the height of the tower in yards? We mark off a line of 7·2 inches on the drawing-board (our scale being $\frac{1}{10}$ inch to a yard), and at each end of the base-line we draw a line running upwards at an angle of 70°. This gives us a triangle. (It is only for convenience that we have made it an isosceles triangle.) The height of the perpendicular drawn from the base to the apex of the triangle is 9·9 inches; our scale being $\frac{1}{10}$ inch to the yard, the height of the tower is accordingly 99 yards.

What we have in this case done by constructing a triangle with rule and protractor, engineers and astronomers do by means of trigonometry (which means, measurement by means of triangles). The distances of the Sun and the Moon have been measured by trigonometry. Our little experiment will have convinced us that in order to measure the distance of the Moon with any accuracy we must employ a very long base-line; for example, a line extending from Greenwich to Cape Town. But it is obvious that if instead of a straight line we have to employ, as our base, a long curve that follows the spherical surface of the Earth, our calculations will be considerably complicated. This is no time for a lesson in spherical trigonometry. All I wish to do is to convince the uninitiated that it is possible to measure the distance of a body in space.

CHAPTER IV

THE REALM OF THE PLANETS

The very first astronomers were probably the shepherds, who, many thousands of years ago, grazed their herds upon the uplands, and communed with the starry sky on cloudless nights. Many of the names which have been given to the stars plainly refer to the ideas and beliefs of a very primitive humanity. The stars were the heavenly clock of these early shepherds, and with the help of the stars they devised their primitive calendar. Not the rising and setting of the Sun alone, but that of the constellations also told them the time, and the appearance of certain stars was a warning to seek shelter with their flocks and herds, because the rainy season was at hand.

The first shepherd astronomers must have made the discovery that amidst the many stars that we to-day call the fixed stars there were a few especially brilliant stars which behaved in a different manner. There was one bright star which was visible only in the morning, which shone with a strangely beautiful brilliance. It became visible only a few hours before the Sun, and was the last of all the stars to disappear, still faintly shining even as the Sun was rising. Another star was known as the evening star, and could sometimes be seen even before the Sun had set. It was afterwards discovered that this evening star was identical with the morning star. It was Venus—the Aphrodite of the Greeks, the symbol and goddess of love and beauty.

Another star was red—red as war, red as fire—Mars. Sometimes it shone with conspicuous brilliance, sometimes with a light so modest that it was hardly to be noticed amidst the multitude of the stars. Another of these peculiar stars was the brilliant Jupiter; another was Saturn, and another Mercury. In all, there were five which seemed to differ from the other stars. Their most conspicuous characteristic, which could not fail to impress any attentive observer, was not their colour, nor their variable brilliance, but their enigmatical movements. They took part, of course, in the daily revolution of the starry heavens, and, like Aldebaran, Castor, Pollux, Regulus, and Spica, which could be combined with other stars in definite patterns or constellations, they moved in uniform circles round the axis of the firmament. Yet the brilliant Jupiter, for example, would one year be shining in the Bull, the next year in the Twins, and the year after that in the Crab—perhaps beside the little group of stars which we call the Manger. In something like twelve years Jupiter would make a complete circuit of the Zodiacal belt. Observers would soon notice that Saturn also wanders through the signs of the Zodiac, though it takes nearly thirty years to complete the journey. Just as the Moon goes its way heedless of the clustering stars, so Saturn, Jupiter, Mars, Venus, and Mercury follow their several paths. Hence they were called the "wandering stars" or planets, from the Greek *πλανήτης*, which means the "wandering stars".

. . . . .

If we observe one of the planets—Venus, for example—day by day, marking on a star map its position among the fixed stars, we shall find that in the course of the weeks, months, and years its path displays some very singular curves. Like all the rest of the planets, Venus keeps (though only approximately) to the Zodiacal belt, and for the most part of the time moves among the stars in a direction opposed to the diurnal rotation of the heavens. Then it slows down, comes to a standstill amidst the stars, and begins to move in the opposite direction, sometimes crossing its own track, so that the latter displays the most curious kinks and loops.

In our sketch of the track followed by Mars in the year 1924 (Fig. 10), the quadrangle and the small triangle show the principal stars of Aquarius. The stars represented by the black points are "fixed stars"; to-day, to-morrow, and every day they occupy the same position in the heavens. Against the background of this group of fixed stars we have drawn the path followed by the planet Mars from June to November 1924. Such loops, which seem as though they could not be due to mechanical forces, must have appeared very strange and mysterious to the simple-minded observers of antiquity. Inevitably they credited the wandering stars with wills of their own; finally they attributed mysterious powers to these heavenly bodies, powers which enabled them to influence the lives of men. The planets were believed to be gods.

. . . . .

It needed, of course, something more than direct

observation to show that our Sun, though there are no loops in its track, passes, in the course of the year, through the signs of the Zodiac. It is not surprising that the Sun and the Moon were included in the ranks of the planets. And thus we get the seven stars which

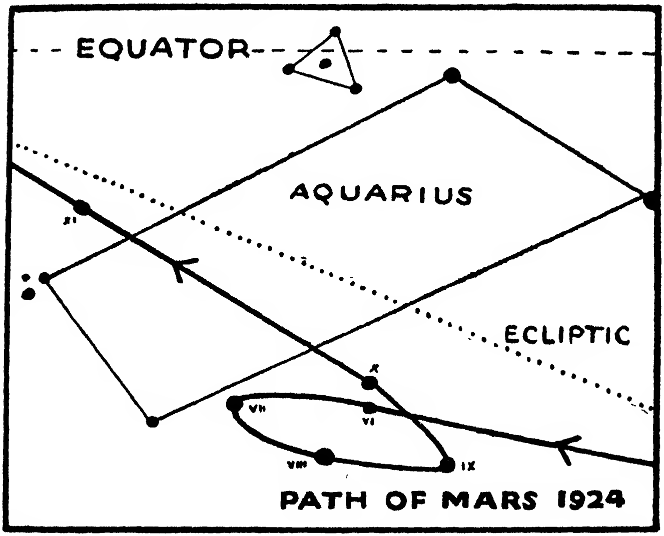

FIG. 10.—The Loop in the Path of Mars, 1924.

were supposed to influence the destiny of human beings.

Undoubtedly, as Schopenhauer says, "even the most casual event is a necessity that arrives by the remotest paths"; but there are influences which any reasonable mind must regard as too infinitely small to play any part in our lives. We know to-day that all theories as to the connection between the positions of the planets

and the destinies of men are worthless and untenable. Astrology may perhaps provide the poet and artist with occasional motives; for others it is at best a fad, a hobby.

In the "family almanacs", however, we find relics of this old belief. We read, for example, that this year Mercury, or Jupiter, or Saturn is the "ruling planet". What this means I will explain.

. . . . .

The ancients arranged the planets in the following manner: Saturn was the first planet, Jupiter the second, Mars the third, the Sun the fourth, Venus the fifth, Mercury the sixth, and the Moon the seventh. The seven planets are here arranged according to the periods of their "revolutions" through the Zodiac.—The seven days of the week take their names from these planets, though some of the Latin gods or goddesses seem to have become German or Scandinavian. It was assumed that each hour in the day was ruled by one of this series of planets. Saturn, for example, ruled the first hour of Saturday, the day named after him; Jupiter the second, Mars the third, and so forth; so that Saturn ruled again in the eighth hour, the fifteenth, and the twenty-second. The twenty-third and twenty-fourth hours were ruled by Jupiter and Mars respectively, so that the twenty-fifth hour, or the first hour of the following day, was ruled by the Sun, and the day was therefore called Sunday.

If we continue through the whole series we find that the Moon is the ruler of the next day, Monday, Mars

of Tuesday, Mercury of Wednesday, Jupiter of Thursday, Venus of Friday, and Saturn, once more, of Saturday.

But the theory of "ruling" planets was carried still farther. Each planet was said to rule, not only certain hours of the day, but also individual years; hence the origin of the still surviving "septennial cycle", on which is based the so-called "centennial weather-calendar", which, if we are to believe those who believe in it, is never mistaken. It is in reality a "seven-year calendar", in which the weather-forecasts recur with beautiful regularity every seven years.

In order to avoid confusion, we ought to call the seven planets of this series the "old planets", or "the planets as known to the ancients", for since the time of Copernicus the Earth itself has become a planet, and it is no longer customary to give the name of planet to the Sun or the Moon.

. . . . .

If we now sum up what we have learned, we may describe the "ancient" firmament as follows: The Earth occupies the central point of a crystalline, starry sphere, in which many constellations are seen besides those of the Zodiacal belt. In this spherical firmament the "old" planets revolve round the Earth, subject only to their own caprices: like the gods, with whom they were indeed identified. But even the gods could not hold in check the geometrical talents of the Greeks.

Ptolemy succeeded in explaining, for example, why Jupiter, when opposite the Sun, or "in opposition",

is obliged, like Mars, to follow a looped path. And this is what Ptolemy taught: Jupiter, unlike the Sun, does not follow a circular path through the signs of the Zodiac. There is, moreover, a certain "point", appertaining only to Jupiter, and lying quite outside it; a something, or nothing, pursuing its own path in space. This point revolves round the Earth once in every twelve years. And round this point Jupiter revolves in a smaller circle, an "epicycle". Finally, the planes of these two circles are slightly inclined to one another. Hence the singular to-and-fro movement of the planet. The peculiarities of the movements of the other planets are explained in the same way. This explanation of Ptolemy's, strange as it may sound to us, is not only highly ingenious: it is, subjectively speaking, perfectly correct. Seen from the Earth, all the planets do actually move as the "Ptolemaic system" requires that they should, in cycles; but quite a number of geometrical refinements were introduced in order to dispose of any discrepancies between the Ptolemaic theory and the movements of the heavenly bodies.

From a purely "terrestrial" or subjective point of view, Ptolemy was perfectly correct. But it was a great achievement to liberate our earthbound ideas, and to inquire whether, if regarded from another and remoter point of view, the movements of the heavenly bodies would not describe figures of greater simplicity. And this achievement we owe to Copernicus.

What was the nature of his achievement?—He asks us to leave the Earth, and to observe the Sun and the

other "wandering stars" from a loftier standpoint. If we consider the Sun as the central body, then not only Mercury and Venus, but the Earth as well revolves round the Sun; then come the orbits of Mars, Jupiter, and Saturn; and according to this new doctrine there are no curious loops in their orbits, for they move round the Sun in simple circles. The Sun becomes the central star, and the Earth becomes a planet.—Since the days of Copernicus the name of planet has been given only to those heavenly bodies which revolve round our Sun, and are illumined by the rays of the Sun, having no light of their own. Until the year 1781 Mercury, Venus, the Earth, Mars, Jupiter, and Saturn made up the tale of the planets. But in 1781 Uranus was discovered, and in 1846 Neptune.—To-day, however, it is quite usual to speak of the planets of other suns, while the bodies which circle round the planets are known as "secondary planets" or "moons".

Ptolemy and Copernicus!—We might express the difference between them simply by saying that a "Ptolemaian" stands on the Earth, while a "Copernican" takes up his position on the Sun. Each takes his pen and describes the movements of the "wandering stars". Each truthfully records what he sees. And each of them is justified; as we shall admit if we realize the profound truth of Kirchhoff's words: that no explanation of the universe can, scientifically speaking, be anything more than a *description* of the universe. Our modern philosophy admits of no "conflict" between the Ptolemaic and Copernican doctrines;

they are simply two different standpoints from which our solar system may be considered.

. . . . .

Both doctrines, however, had to undergo certain corrections. Ptolemy assumed different centres for the orbits of his planets; he made them move in "eccentric circles"; while Kepler replaced the circular orbits of Copernicus by almost circular ellipses.

With these improvements, the old cosmology and the new are both, in one sense, correct. We may say that the Earth moves round the Sun, or we may say that the Sun moves round the Earth; and whichever we say we shall be right. We can only conceive of their movements *relatively*. Yet we may ask: Are both views equally *practical*? Is it, for example, practically advantageous to resort sometimes to the one system and sometimes to the other?

Yes, it is. When making direct observations of the Sun with the naked eye or the telescope we may regard the Sun simply as a moving body, rising in the East and setting in the West. But if we wish to form conclusions as to the structure of the universe as a whole, we must make the more massive Sun the centre of our system, and must consider the firmament from this more advantageous standpoint. And here the advantages of the Copernican system are plainly apparent. It is able to explain the mechanism of our planetary system in an infinitely simpler manner than was possible to the ancients with their epicycles.

. . . . .

Let us look at our solar system—enlarged by the addition of Uranus and Neptune—with Copernican eyes. (See Table of Planets, p. 110.)

In the centre is the Sun; round it circle the planets. Nothing could be simpler. And before we leave our own little universe for the "fixed" stars of remoter space, we will try to get a really clear idea of our solar system, by having recourse to a reduced model.

We will construct our model on the scale which is already familiar to us: 1 to 1 milliard; and we will describe all the necessary circles on the map of a city. We will choose some conspicuous point—the cathedral, or the city hall—for the centre of our system, where the Sun sits enthroned. We shall have no difficulty in representing the planets and their orbits on the scale we have chosen, and we can very well project the whole solar system, with the planetary orbits, on the familiar environment of our own home. We might call this reduced scale of 1 : 1,000,000,000 our "planetary scale".

1 millimetre on the pavements of the city = 1,000 kilometres.

1 metre on the pavements of the city = 1,000,000 kilometres.

The Sun is as big as a coach-wheel. Mercury is a small pea; Mars a large one; Venus and the Earth are two hazel-nuts. Mercury circles round the Sun at a distance of 58 metres; Venus, our morning and evening star, is 50 metres farther away. Then comes the orbit of the Earth. Beyond this, 228 metres from

TABLE OF PLANETS

Planets	Diameter in Thousands of Kilometres	Distance from the Sun in Millions of Kilometres	Revolves Round the Sun in		Density	Number of Moons
			Sidereal Period	Synodic Period		
(1) Mercury, ☿	5	58	88 days	116 days	6·2	—
(2) Venus, ♀	12	108	225 days	1 year 219 days	5·0	—
(3) The Earth, ⊕	13	150	365 days	—	5·5	1
(4) Mars, ♂	7	228	687 days	2 years 49 days	3·8	2
(5) Jupiter, ♃	140	778	12 years	1 year 34 days	1·4	9
(6) Saturn, ♄	120	1,400	29 years	1 year 13 days	0·7	10
(7) Uranus, ⛢	50	2,900	84 years	1 year 4 days	1·3	4
(8) Neptune, ♆	55	4,500	165 years	1 year 2 days	1·2	1

the centre, is Mars; and then comes the great Jupiter. He is a giant compared with our Earth, a small melon to a hazel-nut, but a dwarf compared with the Sun. Our model Jupiter will be over 14 centimetres in diameter, and will be about ¾ths of a kilometre from the centre. Beyond Jupiter is Saturn, almost 1½ kilometres from the Sun. It is rather smaller than Jupiter, but is surrounded by a curious ring, which in our model is as big as an ordinary gramophone record, but rather thinner. Uranus and Neptune, the outermost planets, are the size of billiard-balls; Uranus is not quite 3, and Neptune is 4½ kilometres from the centre.

Here are the exact dimensions of the model. It is instructive once for all to describe for oneself such a home-made planetarium.

	Diameter	Distance from Sun
Sun	1·39 metres	
Mercury	5 millimetres	58 metres
Venus	12 millimetres	108 metres
The Earth	13 millimetres	150 metres
Mars	7 millimetres	228 metres
Jupiter	14 centimetres	778 metres
Saturn	12 cm. (ring 28 cm.)	1·4 kilometres
Uranus	5 centimetres	2·9 kilometres
Neptune	5½ centimetres	4·5 kilometres
The Moon	3½ millimetres	Moon to Earth 38 cm.

The distance from the Earth to the Sun might very well be called an "astronomical unit". We will now make another list of the planets, together with the

calculation of their distances. All the figures in this table represent such astronomical units.

Thus, the Earth is one astronomical unit from the Sun. But instead of 1·0 we will, for reasons to be explained, put 0·4 + 2 × 0·3, which amounts to the same thing. And we will do the same with all the distances, so that we can express them all in similar equations. The first term of the equation is always 0·4, and the second a product, obtained by multiplying 0·3 by a factor which in the case of Mercury is 0, in the case of Venus 1, and for the Earth, and the rest of the planets, 2, 4, 16, 32, 64, 128. In the following table the figures in the first column represent the distance of the planets from the Sun measured in "astronomical units". In the second column are the names of the planets, and in the third the calculations which I have just asked you to make, the results of which give us figures which show, apart from very small differences, an interesting agreement with the figures in the first column. The only really great discrepancy appears in the case of Neptune, where the last figure is 38·3 instead of 30·1.

0·4	Mercury	0·4 + 0 × 0·3 = 0·4
0·7	Venus	0·4 + 1 × 0·3 = 0·7
1·0	The Earth	0·4 + 2 × 0·3 = 1·0
1·5	Mars	0·4 + 4 × 0·3 = 1·6
		0·4 + 8 × 0·3 = 2·8
5·2	Jupiter	0·4 + 16 × 0·3 = 5·2
9·5	Saturn	0·4 + 32 × 0·3 = 10·0
19·2	Uranus	0·4 + 64 × 0·3 = 19·6
30·1	Neptune	0·4 + 128 × 0·3 = 38·8

If we interpose an equation between Mars and Jupiter, we obtain an easily recognizable *series* in the second column of figures (ignoring, of course, the 0) which is of such a character that each number is precisely double that of the preceding number: 1, 2, 4, 8, 16, 32, 64, 128. Here we have what is known as the "Titius-Bode rule". The occurrence of this series is something more than a striking coincidence, and it has added greatly to our knowledge of the structure of the planetary system: as I shall now explain. At the end of the eighteenth century the outermost planet, Neptune, which shows a marked deviation from our rule, was not yet known. It was discovered as lately as 1846, and Uranus in 1871; so that the Titius-Bode rule used to show an even closer agreement with the actual data. The interpolated fifth line in our table, which appeared to fill a gap, made the astronomers suspect the existence of a hitherto unknown planet. But no such planet was to be seen. It was impossible to believe that it could have escaped the observation of the astronomers, for at this comparatively short distance from the Earth an object of any size must sooner or later have been observed. There was only one possible explanation. Ages ago, perhaps, a planet did revolve round the Sun, at a distance of 2·8 astronomical units, and was shattered by some sort of catastrophe, by a collision of some kind, so that the telescopic fragments—possibly in great numbers—were still circling in a girdle round the Sun. The astronomers sought and sought for the fragments—and not in vain.

. . . . .

The Italian astronomer Piazzi was the fortunate discoverer. It was on the very first day of the new century, January 1, 1801, that Piazzi, in his observatory at Palermo, observed a small planet which appeared to be at approximately the required distance. Even by ordinary standards it was a small body, being only some 500 miles in diameter, and measured by our planetary scale a mere millet seed, on which our Earth, large as a hazel-nut, might well look down with scorn, if "up" and "down" had any existence in the universe. This new addition to the planetary series, dwarf though it was, received the name of a goddess, Ceres. In the very next year the physician Olbers, who was in his leisure hours an eminent astronomer, discovered another "planetoid", as these pigmy planets were called. The third was discovered in 1804 by Harding, and in 1807 a fourth was added to the list. The average distance of these "planetoids" from the Sun does not deviate very far from the hypothetical 2·8.

Four planets were thus added to the planetary kingdom, cruising in the space between Mars and Jupiter. This Titius-Bode rule is a classical example of a working hypothesis. Although it seems to be merely fortuitous, and although it does not hold good at the beginning of the series—since 0 is not the half of 1—nor yet at the end, it has none the less enriched our knowledge of the planetary system.

It was Olbers, the discoverer of the second of the minor planets, who made the discovery of 1807.—The years passed, and it seemed quite improbable that any further planetoids would be detected. For thirty-

eight years the list contained only four names: Ceres, Pallas, Juno, and Vesta. But in 1845 a diligent amateur astronomer, Hencke, by profession a postmaster, discovered a fifth pigmy planet, and presently a sixth. The news of his success revived interest in the search, and by 1850 thirteen of these little wanderers had been discovered; by 1860 the list had been increased to 62; by 1870 to 112; by 1880 to 219; by 1890 to 302; by 1900 to 463; by 1910 to 707; and by 1920 to 944; while in 1923 the thousandth planetoid or asteroid was detected, and was given the name of "Piazzia" in honour of Piazzi.

Well over a hundred of this great swarm of asteroids were detected by the watchful eye of one Johann Palisa, and after Max Wolf of Heidelberg had begun, in 1890 or thereabouts, to employ photography in the search, thereby greatly expediting the work of discovery, he won undying fame by his diligence in watching and identifying the minor planets—and it will be understood that the task of keeping them all in view is infinitely exacting. In 1906 the French Academy bestowed the Valtz prize on Palisa, on the grounds that "in respect of the discovery, identification, and observation of planets he had done more than all other astronomers put together".

To-day we know of over a thousand minor planets, the little brothers and sisters of the Earth. Many of them have beautiful names—the names of goddesses and nymphs and heroines—for the discoverer has of course the privilege of christening his discovery. After a time, however—whether the supply of suitable names

gave out, or whether the astronomers grew weary of selecting them—they were denoted simply by the year of their discovery and one or two letters of the alphabet.

. . . . .

The solar system of the Sun and planets has been called our astronomical home; our *astronomical* home, for it is only the telescope that enables us to visit its different regions. It is now time for us to learn something more of our neighbours. Let us turn our telescope upon the planets.

The Earth has two neighbours—much more distant than the Moon—which are very different in character: the "lovely Venus" and the "warlike Mars".—But I doubt if our astronomers take much account of the pugnacity of Mars, for our ruddy neighbour is old, very old; much older than the Earth. There are good reasons for assuming that the age of a planet bears some proportion to its distance from the Sun. "Venus is Youth; the Earth, maturity; Mars, old age"; so the astronomer Coblentz qualified the three planets.

Of Venus we can learn but little by observation; when seen through the telescope her brilliance is so dazzling that it is impossible to distinguish any definite details on her surface. That she is a sphere, giving out no light of her own, but merely illumined by the Sun, was known to Galileo, the first to observe her phases, which change like the phases of the Moon. Venus, as our table shows, travels through the twelve signs of the Zodiac in about seven months. This is the

period of her sidereal revolution. But in order to overtake the Sun again—for meanwhile the Sun too has been voyaging through the Zodiac—she needs a few months longer. Relatively to the Sun, her period is 1 year and 219 days. To this day we have been unable

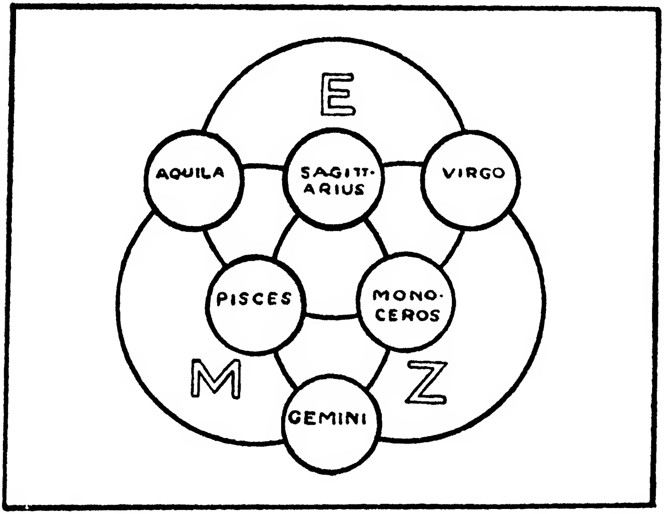

FIG. 11.—The Constellations in which the Three Circles—Equator, Ecliptic, Milky Way—intersect one another.

to determine how long her snow-white body takes to rotate upon its axis. We do not know the length of her days and nights. All that we do know is that the whole planet is wrapped in a dense veil of dazzling white clouds; for research and experiment have told us the reflecting power of white clouds at any given distance.

Venus, under normal conditions, can approach to

within about 25 million miles of the Earth (measured by our planetary scale, the two planets would be two hazel-nuts 40 metres apart), but she then turns her unlighted side to the Earth. Some thirty-six days later she is seen shining with great brilliance to the right of the Sun; and the telescope shows her as a beautiful silver crescent. She is then the "morning star". Continuing on her journey round the Sun, she recedes to a distance of 160 million miles, and then, some thirty-six days before attaining her closest proximity to the Earth, she is seen, at her brightest, as the "evening star".—Just as the Moon does not eclipse the Sun every time it passes between the Sun and the Earth, so Venus does not cross the disc of the Sun, looking like a small black beauty-spot, every time she passes between us and the Sun. Such "transits" of Venus are very rare. One occurred in 1874, and another in 1882; the next will occur in 2004, to be followed by another in 2012.

. . . . .

Mars is better known to us. Its surface can be closely studied with the telescope. We know, for example, that it is an almost perfectly smooth sphere; its mountains are at most 3,000 feet in height. It circles round the Sun in 687 days, and once about every two years it closely approaches the Earth. Unlike Venus, whose orbit lies within that of the Earth, so that she can never be seen shining opposite the Sun as a "midnight" star, it is precisely at midnight that Mars can be best observed. But the "oppositions" of Mars are not all equally favourable to observation, as its orbit

is strongly elliptical. The opposition of 1924 was particularly favourable to observation, and I need hardly say that the astronomers made the most of this opportunity of studying the planet. Graff, in Hamburg, published some very fine pictures of Mars. The next really favourable opposition will occur in 1956, and the next after that in 1971.

I know what my readers would like to ask me. I am not unmindful of my obligations, but we will discuss the question of the "inhabitants of Mars" in a later chapter.

Mars is at all events no old bachelor; he has two sons, two such nice little fellows that it was really too bad of the astronomers to call one "Fear" and the other "Terror"—"Phobos" and "Deimos". These little satellites are so small that one could easily walk right round either of them in a few hours. They are positively only a few miles in diameter. On our planetary scale they would be mere specks of dust, a hundredth of a millimetre in diameter, revolving at distances of 9 and 23 millimetres round a Mars 7 millimetres in diameter. The nearer of these little moons makes the circuit of Mars in eight hours; the outer moon in thirty hours.

. . . . .

The planet nearest the Sun is Mercury. Of him there is not much to be said. To the ancient Greeks, Mercury was the god of merchants—and the protector of rogues and thieves. It persists in keeping so close to the Sun that it is not easy to observe it. Astronomers believe that it always turns the same side to the Sun. If this

is the case, the temperature of the sunny side of the planet must be so high that all the moisture must have withdrawn to the dark side, where it is presumably congealed into ice. One thing we do know for certain —that if only the Atlantic Ocean were deep enough, and Mercury were dropped into it, there would be plenty of room for it between the Old World and the New.

. . . . .

Mercury, Venus, the Earth and Mars are followed by the swarm of the minor planets or asteroids. Our modern astronomers have applied statistical methods to the study of these bodies, and have achieved remarkable results, so that this company of little planets is beginning to acquire greater and greater significance. Nevertheless, the individual asteroids seldom attract much attention, unless the orbit of one of their number should show conspicuous deviation from the orbits of the majority. For example, in 1931 the planet Eros will pass unusually close to the Earth, so that the conditions will be favourable for determining its precise distance, and this will make it possible to verify that very important value—the distance from the Earth to the Sun.

. . . . .

Let us now look at Jupiter through the telescope. We shall see a perceptibly flattened sphere, and we shall find that in spite of its enormous mass the planet rotates upon its axis in about nine hours. The dark,

parallel streaks on the bright disc, sometimes interrupted by brighter ovals, are conspicuous features. The diameter of Jupiter is as much greater than that of the Earth as the diameter of the Sun is greater than that of Jupiter. Not only as regards its diameter, but also in respect of its physical constitution, Jupiter may be regarded as "half-way between the Earth and the Sun". On the one hand it is a planet, like our Earth; on the other hand, its nucleus, which is intensely hot, is surrounded by an enormous gaseous sphere, whose outer stratum we see as a layer of clouds. As a ball of gas, therefore, it is akin to the Sun.

What makes Jupiter such a fascinating object for observation, even through a small telescope, is its quartet of four "bright" moons, which are seen sometimes to the left of the planet, sometimes to the right, constantly forming a different pattern, and sometimes casting their shadows on the bright disc of the planet, so that the picture of Jupiter with its moons is one that is constantly changing. Calculation tells us that any given arrangement of the moons cannot occur again until twenty-five years have passed. One of the most interesting times to observe Jupiter is the moment when one of the moons disappears in the shadow of the planet, or emerges from it into visibility.

The four "old" moons of Jupiter were discovered by Galileo in 1610. To-day we know of five more, one of them revolving inside the original four, and the other four circling round the planet at a very great distance; and these, unlike the four discovered by Galileo, which revolve almost in one and the same

plane, circle round the planet in orbits which diverge from this plane so considerably that it has been assumed that they did not originally belong to the system of Jupiter, but were at one time minor planets, which were captured by the great planet, and retained as moons.

We have already seen that the orbits in which the planets revolve round the Sun are not perfect circles, and that it was Kepler who first succeeded in giving a satisfactory explanation of the movements of the planets by replacing the Copernican circles by ellipses, one of whose foci is occupied by the Sun. That the planets revolve in such elliptical orbits is known as the "first law of Kepler". The second law of Kepler relates to the velocity of the planets. A planet moves more rapidly in that part of its orbit which is nearer to the Sun than in that part which is more distant from it, and further, its velocity varies in such a manner that a line connecting the Sun and the planet will always describe, in equal times, equal areas of the elliptical orbit.

The third law of Kepler may be illustrated by a simple calculation: half the major axis of the ellipse in which Jupiter moves, the so-called "mean distance" from the Sun, which we have hitherto described (in the table of planets and elsewhere) simply as the distance from the Sun, measures 5·2 astronomical units, while the period of revolution about the Sun is precisely 11·89 years.—Now let us multiply the distance by the distance, and again by the distance, and the sidereal period by the sidereal period.

We then have:

$$5 \cdot 2 \times 5 \cdot 2 \times 5 \cdot 2 = 141$$
$$11 \cdot 89 \times 11 \cdot 89 = 141$$

in round figures, omitting decimals.

We obtain, therefore, the same product, whether we multiply the distance from the Sun twice by itself, or the period of revolution round the Sun once by itself. This fact—though it is usually expressed in a different fashion—is known as the third law of Kepler.

This law enables us, having observed the sidereal period of a planet—for example, of a newly discovered minor planet—to determine its distance from the Sun (expressed in astronomical units), for we have only to multiply the sidereal period by itself and to extract the cube root of the product.

. . . . .

Now we come to Saturn, the "ringed planet". Seen through the telescope, it appears as a slightly flattened, faintly striped sphere. We know beyond a doubt that what we are looking at is not merely a dense atmosphere shrouding a solid body, but that the whole planet is a ball of gas. Its specific weight is only 0·7, so that it is light enough to float in water. Round the sphere floats a great ring, and outside the ring no less than ten moons revolve round the planet.

The sphere revolves upon its axis once in ten hours. The ring is unique. The only thing with which we can compare it is the swarm of asteroids. Just as a thousand or more relatively minute bodies revolve about the Sun, so countless little fragments of worlds,

perhaps the remnants of some larger body, circle round the sphere of Saturn; though to us they have the illusive appearance of an unbroken ring. We know this from our researches with the spectroscope, and from our measurements of the reflective capacity of the ring in respect of the sunlight that falls upon it. Both methods of research give the same result: the ring consists of small particles, of meteorites, which, independently of one another, in accordance with Kepler's laws, circle round the sphere of the planet like so many tiny moons. In some areas these tiny moons appear to be less thickly congregated: as, for example, on the inner rim of the ring-system. We can see the sphere of Saturn shining through the innermost portion of the ring, the "crape ring", as it is called. In certain places the ring is divided by concentric lines. In "Cassini's division", for example, which may be seen through a comparatively small telescope, and in the "pencil lines",[1] the tiny moons appear to be completely absent.

Since the days of Galileo the telescopic image of Saturn has undergone many developments. Huygens, the inventor of the pendulum escapement, and the founder of the wave theory of light, was the first to recognize that the ring floats unsupported in space; and it was he who discovered, in 1655, the first of Saturn's moons. In the seventeenth century Cassini discovered four further moons; Herschel, in 1789, discovered two more; Bond, in 1848, added one to the list, while the ninth and tenth were observed by Pickering in 1897 and 1904 respectively.—The great

modern authority on the Saturnian system is Georg Struve, "Struve the fourth", a member of a family which has produced famous astronomers in four generations.

. . . . .

If we could journey to Saturn by rail, how long would it take us?—Saturn is almost ten times as far as the Sun, and we have seen that a railway-train would take four hundred years to reach the Sun. We should have to travel, then, for nearly four thousand years! Even the swift light of the Sun takes over an hour to reach the ringed planet. Once there, we should live in an eternal twilight, for the sunlight on Saturn is almost one hundred times weaker than on the Earth, and we should certainly be frozen there but for the heat emitted by the planet itself.

. . . . .

Until the year 1781 the orbit of Saturn was the limit of the planetary system. Beyond it was the endless gulf that divides us from the fixed stars. But in 1781, by a mere chance, the bounds of our planetary system were enlarged. William Herschel discovered a new planet, to which he gave the name of his king. But this name has not been adopted. The father of Mars, according to the ancient sages, was Jupiter, his grandfather Saturn, and his great-grandfather Uranus; and Uranus was the name chosen for Herschel's planet.

It was, as a matter of fact, discovered that Uranus, from 1690 onwards, had been marked on various maps of the heavens, but had been mistaken for a fixed star. Indeed, it is not impossible—though no one can say that it is certain—that it may have been occasionally

observed by astronomers even before the days of telescopes, for it is, after all, a star of the sixth magnitude, and it can be distinguished with the naked eye if it happens to be in a part of the sky that is not too rich in stars. I myself have seen it repeatedly without a telescope, and have had no difficulty in pointing it out to others. In the telescope it appears as a greenish-grey disc; no details can be distinguished. Its structure is like that of Saturn; it is a ball of gas with a solid centre; but Uranus is very much denser. And Uranus, like Saturn, has moons; four are known to exist. The plane of their orbits is almost at right angles to that of the orbit of Uranus.—The planet takes no less than eighty-four years to circle once round the Sun.

. . . . .

The calculation of the orbit of Herschel's planet did not present any special difficulty. At the same time, it was evident that the astronomers must, as always, be prepared for slight discrepancies between theory and observation. Before long, however, the new planet had begun to puzzle the mathematicians. Despite the greatest accuracy, and although allowance was made for the fact that Jupiter and Saturn might produce certain perturbations of the planet's orbit, many of the calculations proved to be erroneous. It was therefore suspected that there might be yet another, unknown planet beyond Uranus, and that the attraction of this planet might be causing the perturbations. This planet would, of course, have a definite mass, and would move in a determined orbit, at a definite distance from the Sun, and would affect its neighbour Uranus in propor-

tion to its nearness or remoteness. So much was evident, but the calculations involved were extremely complicated, since the mathematicians had not merely to prove the existence of the unknown planet, but also to state precisely where it would be found at a given moment.

Two astronomers, Adams in England and Leverrier in Paris, calculated the position of the new planet, independently of one another, and both obtained a correct result, though in other respects they were not equally fortunate. Leverrier, unlike Adams, was able to confirm his calculations by visual observation. He had no astronomical chart of the region in question which would enable him to distinguish the little point of light in the midst of hundreds of other stars. He wrote to Galle in Berlin, who, as he was aware, possessed excellent charts of the heavens; and on the very evening when he received the letter from Paris—it was September 23, 1846—he went to his observatory, and found the planet. In the same year Lassell discovered a moon, which revolved round Neptune in something less than a week.

. . . . .

We have now come to the end of the planetary system. Whether, beyond the orbit of Neptune, still other bodies are circling round the Sun, we do not yet know.[1]

It is conceivable, as is the possibility that still other small planets have their orbits within that of Mercury.

Neptune is thirty times as far from the Sun as our Earth, and it takes no less than 165 years to complete one revolution of its orbit.

[1] See footnote on next page.

If we turn to our table of planets (p. 110) and compare this *sidereal* period with the *synodic* period, we find that the latter is only one year and two days. We shall see that the outer planets take less time to return to their closest apparent proximity to the Sun in proportion as their actual distance from the Sun is greater.

A fixed star has a synodic period of precisely one year. This means that a very distant planet would move so slowly that it would be very difficult to distinguish it from one of the fixed stars.

It is conceivable that there is a "trans-Neptunian" planet;[1] there may even be several such; but for the reason given above, and because of the presumably faint luminosity of these problematical bodies, the question of the ultimate limits of the planetary system is still an open one. The sovereignty of the Sun, however, extends far beyond the orbits of the planets, for his power over the comets makes itself felt at distances many times greater than the diameter of Neptune's orbit.

[1] [Since the above lines were written the astronomers of the Lowell Observatory at Flagstaff, Arizona, have reported the discovery of the suspected trans-Neptunian planet. This discovery is the culmination of fifteen years of research and observation. The late Dr. Percival Lowell computed that the unknown planet should revolve round the sun in a little less than 300 years, at a distance of over 3,270 million miles. According to the data at present available the new planet revolves round the sun at a distance of forty-five astronomical units, or 4,185 million miles (departing altogether from the Titius-Bode rule), in a period of something over 300 years. Its luminosity is that of a star of the fifteenth magnitude, and its mass is believed to be seven or eight times that of the earth. No satellite has been detected.—The data as yet available are so indefinite that they do not exclude the possibility that the new body may prove to be a comet.]

CHAPTER V

ARE OTHER PLANETS INHABITED?

WHEN one has been for seven years a director of a public observatory, so that on almost every clear night one has allowed inquisitive visitors to look through the telescope, and when one has made scores and scores of nocturnal excursions, with people, young and old, of every class and every degree of culture, one becomes familiar with a series of stereotyped questions which must always be answered with the same cheerful assiduity.—What is the magnifying power of the largest telescope in the world?—What is the best book to read if one wants to learn something of astronomy? —and thirdly, though by no means lastly: Is Mars inhabited?—This third cardinal question may be asked with or without introduction, and may be variously worded, but the answer required is always: Yes or No.

Is Mars inhabited?—It is as though my questioners were sorry for the little Earth, which seems so lonely in the great universe; and so they want to know, here and now, what are the conditions of life of the "people" who inhabit the golden-red planet.

. . . . .

But to the general public—whatever their degree of culture—the problem appears an important one; and they often assume that it is equally important in the eyes of those learned in the lore of the stars—that it is,

in short, the most important and essential problem of astronomical science.—And this it assuredly is not. I do not mean to say that the problem of the possible plurality of inhabited worlds is not interesting in itself, and that this interest is not perfectly justified; but it is only one among hundreds of problems, each of which, as soon as solved, confronts us with a hundred others. And here is a curious thing: the problem of the inhabitability of Mars is almost always regarded as identical with the problem of the inhabitability of the whole universe. If Mars is shown to be empty of life, then all the other worlds in the universe are dead, and our Earth is the only World in space which enjoys the distinction of supporting human life. Mars is so popular a planet that people forget to ask whether there may not be other dwelling-places in the vast, round, starry heavens.

• • • • •

About fifty years ago, in Milan, our neighbour was under the constant observation of the astronomer Giovanni Schiaparelli. His telescope was only of moderate power, but no one had any doubts as to the ability of the astronomer to get out of the instrument the utmost of which it was capable. And no one doubted his integrity: he would not profess to see more than he had really seen.—Now Mars, seen through the telescope, shows a reddish-yellow disc, and on this disc certain dark patches are visible. It looks as though the bright patches might be continents, and the dark patches seas or marshes. One can see plainly that Mars,

like our Earth, revolves upon its axis, and at the ends of the axis, at the poles, there are white patches, which may be areas of snow and ice.

The dark portions are sometimes darker than at other times; and the "polar caps" are sometimes larger and sometimes smaller. Incidentally, the assumption that there is a winter and a summer on Mars—that it is summer when the white patches are small, and winter when they are large—is open to question.—On the whole the features visible on Mars are so permanent that Schiaparelli was able to draw charts of the whole of the surface of the planet.

It was only natural that the light and dark areas should be given names. Geography and mythology, being laid under contribution, provided names which had lost something of their lustre since the Renaissance and the circumnavigation of the world. But besides the seas and continents, Schiaparelli saw great numbers of very fine lines which ran hither and thither over the yellow expanses of the globe. Sometimes they formed a sort of pattern which covered the whole surface of the planet, and neither geography nor mythology could provide any suitable name for them. I do not know how long Schiaparelli's embarrassment lasted; but I do know that he finally called the streaks *canali*, which really means "channels". But it was translated as "canals", and this one little word was responsible for turning the attention of half the world to Mars. A canal—and the streaks were not only *called* canals, but all of a sudden they *were* canals—must, as every sensible person would admit, be the

work of engineers, of reasoning beings, of men! Hence the conclusion: Mars is inhabited! The authority for the statement?—the eminent astronomer of Milan! And the proof?—none other than the general enthusiasm over the story of our newly discovered neighbour in the universe! Mars had become the fashion, and although we do not hear much of the planet nowadays, we may be sure that we shall do so when it is once more in a favourable opposition—when it is once more a midnight star, and comparatively near to the Earth.

Needless to say, the astronomers themselves have contributed but little to these fantastic theories. The "canals" were enigmas. Many scientists had a suspicion that they were merely "optical" in character; but it was not until 1924 that Kühl, in Munich, demonstrated beyond a doubt that the "canals" have no real existence, and may indeed be evoked at will, by a simple experiment which I will presently describe.

. . . . .

But what about our Martian engineers? For the moment we will disregard Kühl's demonstration. Is it not conceivable that there are "men" on Mars? Are there not canals there?—Well, both are certainly conceivable, and as long as my questioners will realize that we must not hold a thing to be proved simple because it is conceivable, I will tell you what I know.

Mars is a brother to our Earth. Like the Earth, it consists of matter drawn from the Sun; like the

Earth, it circles round the Sun, though at a greater distance; and there is reason, as we have seen, to believe that it is therefore older than our Earth. The inhabitants of the Earth possess a very ancient civilization; the sum of their discoveries and inventions is truly amazing, and becomes even more so from day to day. But it is quite conceivable that *if* Mars is inhabited, the Martians have long ceased to puzzle their heads over many problems which we may not even begin to tackle for another thousand years.

The canals are intelligently distributed—I will omit the quotation marks, and trust the reader to realize that the omission is only provisional.—They run straight from point to point, constituting the shortest possible connecting lines, and almost without exception they run from sea to sea, from swamp to swamp. They may be traffic-routes through the empty yellow deserts. That they are hundreds and even thousands of miles in length need not trouble us; nor need the objection that their width, which amounts to many miles, represents a technical impossibility. The technical methods of the Martians are more highly developed than ours; moreover, the mass of Mars is much less than that of the Earth, and would not exert so great a force of attraction on the soil as does the Earth. A normal jumper, in good training, could easily jump as high as the ceiling if transferred to Mars, for his weight would be very much less than it is on our Earth. The Martian machines would therefore be more effective, so that our objections are really of no value. We need

not regard the Martian canals with greater respect than our own terrestrial achievements.

. . . . .

We all know how often people have discussed the possibility of receiving signals from Mars. We have even had "Martian" films; for the producers are well aware that the heavenly bodies have "appeal". And many an innocent enthusiast has puzzled his brains to devise means of calling up our celestial neighbour. A goodly portion of the Sahara was to be appropriated for the purpose; an enormous Pythagorean triangle, with the three squares described upon its sides, was to be brilliantly illuminated at definite intervals for the edification of the Martians. They, of course, have enormous telescopes. There is no doubt whatever—so the argument runs—that the Martians, who are far more highly evolved than ourselves, must be familiar with the Pythagorean theorem, and would regard our diagram as the work of rational beings. "When our intention is understood on Mars, they will undoubtedly reply to us with the same luminous diagram, probably in the same tempo."—The whole enterprise would have been much cheaper than—for example—a war; but the necessary funds, for reasons not difficult to understand, were never collected.

Much has been written on the subject of the Martians, both for and against their existence. Those who argued that there were such beings naturally had the best of it, for their opponents' thesis was not in the least interesting. The persistence of those who insisted that

Mars was most certainly inhabited, even though its inhabitants might not be human, was really remarkable, as the following quotation will show. It is quite ridiculous—which is my reason for quoting it!

"The dark seas are as a matter of fact not seas at all, but beautiful green forests. The so-called canals join forest to forest, oasis to oasis. And the forests and oases are inhabited by apes. On their long journeys through the deserts these apes carry fruit. They drop the seeds and stones of the fruit on the caravan routes; the seeds germinate, and grow into trees, green trees, and the resulting avenues are the 'canals'."

The Martian animals are truly ingenious—and so are our journalists!

. . . . .

But now to be serious: how can we prove that the lines on Mars are merely an optical illusion—and even if it is true that the canals have no real existence, are there not other ways of approaching the problem of life on Mars? Cannot modern science find some other way of answering our question?—Yes; it can, as we shall presently see. But first I will tell you how everyone can see Martian "canals" in the daily newspaper, which are just as genuine as those on the red planet.

Take a sheet of paper which is evenly covered with print, and cut out a circular piece, the size of a small plate, to represent Mars. The words and letters are arranged more or less according to chance, though we may possibly find that there is a sort of lane or river of words running diagonally across the text. This,

however, is not what I mean by a canal. But besides these plainly visible and accidental streaks, there are still a great number of similar streaks, though for the moment they are, as we say, beneath the threshold of observation. Still, it takes very little to induce them to become perceptible; it will suffice, for example, if we make two little blots of ink in two different parts of the paper. But the best way of making them visible is to paint an irregular shape—we might make it like a salamander, with a jagged crest—on the upper half of our paper Mars, and to make a few little blots in other parts of the paper, beyond or beneath the salamander. Now, if we hold the paper at a certain distance (the distance, and the size of the blots, and their intensity, must be found by trial), we shall see, some of us at once, and some after a few moments, a number of canal-like streaks, which run always from point to point of the darkened portion, and are perfectly straight, like the canals of Mars. Sometimes a whole system of such "canals" flashes upon us, and it is worth noting that such "canals" are visible even in photographic reproductions of the scrap of newspaper. The problem of the canals, in short, is not astronomical, but physiological. Once for all, therefore, we cannot conclude that there are "men" on Mars on the grounds of their visible technical achievements: for the telescope shows us nothing of the kind.

. . . . .

We know that Schiaparelli was not responsible for the great impatience with which the public demanded an

explanation of the canals on Mars. He merely observed certain appearances, but expressed no opinion as to their meaning. And generally speaking, astronomers and other scientists do not ask themselves whether this or that heavenly body is "inhabited". The most we can reasonably ask is whether the conditions on Mars are such as to offer the possibilities of existence to any sort of living creature. I once put this question to Schiaparelli himself. And this is what the famous astronomer told me in 1906:

"The problem is a twofold one, and we ought really to ascertain, first of all, what are the physical, chemical, and physiological conditions under which organic life is possible. Of these conditions we know little. It is easy to describe a condition of things which would make life impossible. But I do not believe that anyone has ever yet investigated all the combinations of the conditions under which life *is* possible. For this reason, I feel that I am not in a position to answer this part of the question. And besides this, one would have to know what are the conditions which Mars could offer to organic life of this or that nature. Again, we are far from knowing what these conditions are. The telescope tells us little that is relevant. Perhaps it will enable us, in time, with the help of the spectroscope, to analyse the atmosphere of Mars, in order to ascertain the nature of the white substance which forms the Polar caps. But for the moment we have nothing better than contradictory reports to go on." Thus wrote the Milan specialist more than twenty years ago. Now let us see what the scientists

can tell us to-day, as the result of spectroscopic examination.

. . . . .

Although it may seem venturesome to make any exhaustive enumeration of the conditions which would permit of the genesis of organic life, we will at least attempt to do so in relation to the conditions on Mars as we know them to-day. We can name certain fundamental conditions which are essential, if not to the genesis, at least to the maintenance of organic life: certain chemical elements; light and heat; a sufficiency of water; an atmosphere containing oxygen; and lastly, a moderate gravitational force, which will permit of the necessary movements of living creatures.

1. *Chemical Elements.*—The following chapter on "Comets and Meteorites" will confirm us in the opinion, already expressed, that all the bodies in the universe are formed of the same substances, of the same hundred or so of chemical elements. Of these elements, those which are quite peculiarly essential to life are carbon, nitrogen, oxygen and hydrogen.—These four elements can be proved to exist on Mars, and with them sodium, magnesium, iron, sulphur, and other elements which, as far as we know, are essential to life. "We may at all events be sure", says Schwarzschild, "that we should not find, on other planets, quite different systems of chemical elements; that at ordinary temperatures liquid gold could not be poured out of beakers of solid air; we know that there would be no such crazy violations of terrestrial

possibilities."—So, as regards the chemical constitution of the planet, we cannot deny the possibility of organic life on Mars.

2. *Light and Heat.*—Mars is considerably farther from the Sun than the Earth, yet it still receives abundance of light. The temperatures prevailing on the planet were measured by Coblentz on the occasion of the last favourable opposition. Here are the results; they are not uninteresting:

South Polar region	$-10°$ to $+10°$ C.
South temperate zone	$+10°$ to $+20°$ C.
Centre of disc	$+20°$ to $+30°$ C.
North temperate zone	$+5°$ to $+15°$ C.
North Polar region	$-25°$ to $-40°$ C.

In respect of light and heat, then, we are still unable to say that life could not exist on Mars.

3. *Water.*—There is undoubtedly water on the planet, though only very little. John and Adams, in 1924, concluded, as a result of their observations, that the Martian atmosphere contains only one-twentieth of the proportion of water-vapour contained by the atmosphere of the Earth. In these observations the spectroscopic lines of water-vapour in the Martian atmosphere were compared, in respect of their intensity, with the well-known lines of water-vapour in the Earth's atmosphere. That it was possible to distinguish the two sets of lines is explained by "Doppler's principle". Mars and the Earth were in motion relatively to one another, with the result that the lines of the Martian spectrum were slightly displaced.

The dark areas of the planet may be seas, though

they are probably very shallow, and the white caps snow and ice, though it is suspected that they may actually consist of ice-clouds, floating at no great distance from the ground, rather than a solid deposit of snow.

4. *Atmosphere.*—It has been demonstrated that Mars has an atmosphere, but it is not nearly so dense as our earthly atmosphere. Adams and John have estimated the oxygen content of the Martian atmosphere as approximately 15 per cent. of that of our atmosphere. We see once more that we can hardly deny the existence of Martian "inhabitants"; though on account of the thinner atmosphere they may be very different in form and character from the inhabitants of the Earth.

5. *The Force of Gravity on Mars.*—We have already considered this point sufficiently. The relatively small attractive power of our neighbouring planet would apparently make life there more supportable than on our heavy Earth.

. . . . .

Further, the scientists cannot say that the climatic conditions of the planet are *not* such as to make the existence of life possible. But can they say that life *does* exist on Mars?—No. Mars is and remains an enigma, but only a very impatient person will be angered by its mystery. It may be that later generations will achieve more definite knowledge of the planet. There are those who believe that the climate of Venus is more fitted to support life than that of Mars. Mercury

is, of course, so near the Sun, and of the other planets some are so far from it, while others are still so shrouded in hot vapours, that it may be millions and millions of years before conditions will occur which would make it possible for organic life to be engendered. We cannot, therefore, declare with certainty that any of the planets—excepting the Earth—are inhabited. But to those who realize that the universe does not end at the orbit of Neptune this result is not very important. We know that there are stars which are hundreds and thousands of light-years distant from us, while a ray of light from Neptune will reach us in a little more than four hours. Compared with the greater universe which we call the *galactic system*, our solar system is like a penny-piece compared with Europe. In this universe there are something *like thirty thousand million* suns like our Sun. Would it not, then, be altogether too naïve to assert that life exists only on the surface of our little Earth?

. . . . .

The problem, however, is rather more complicated than it appears at first sight. For there are good reasons for assuming, as we shall learn from a later chapter, that the planets, including the Earth, could only have been drawn out of the maternal body of the Sun by the agency of a tide set up by another sun. The countless stars—all suns—that fill the universe are indeed a mighty host, and they are all moving, in relation to one another, with terrific speed, like the midges in a swarm, so that at one time another star may have approached our Sun.—How great is the probability

that two such stars should approach one another so closely, drawn together by mutual attraction, that each would set up a tidal movement in the other which would force it, as it were, to give birth to offspring?

First of all, let us try to get a very rough idea of

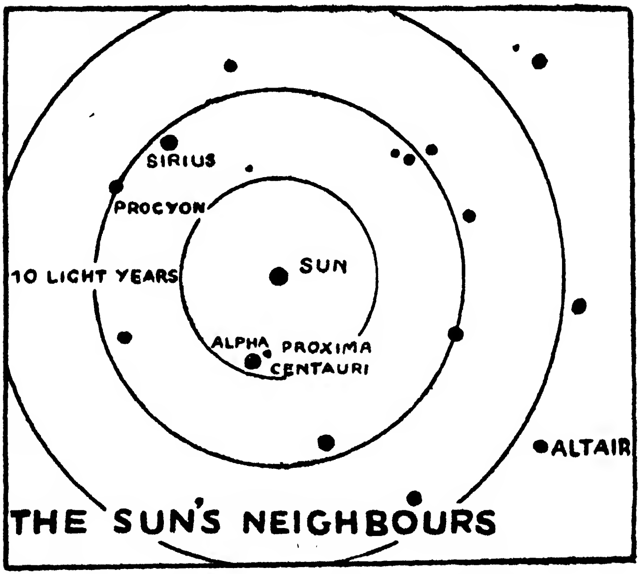

FIG. 12.—The Sun and the nearest Fixed Stars.

the relative distances between the stars. Let us imagine that the stars are as small as particles of dust, and indeed even smaller. The distances between these particles of dust will amount to *miles*; here is a speck of dust on the pavement; the nearest is a mile or two distant.—No matter how frantically these particles of

dust may be whirling about, the probability of two colliding is practically *nil.* Now, in modern astronomy there is no such thing as "nil", just as there is no such thing as a "world without end". It is possible to calculate—it is easier to do so than the uninitiated would imagine—that a new planetary system, like our own, might come into existence about once in ten thousand million years. This, to be sure, would not be a very high birth-rate. Only once in ten thousand million years do the distant sisters of our Sun give our Earth new cousins! And it is not so very long ago that ten thousand million years was believed by the scientists of the day to be the age of the whole Milky Way! When we consider this fact we can understand the opinion, which not long ago was held by the best authorities, that our planetary system may be *unique* in the universe. There are people who find something sublime in the idea that we earthly humans are the only rational beings in the whole universe. To them the result of this calculation of the probability of another planetary system must have been most gratifying.

. . . . .

But mathematics has never yet succeeded in adducing a new truth so long as the bases of calculation were insufficient. To-day, since our astro-physical methods have been continually modified by the immense progress of physical science, we are in a position to draw much more reliable conclusions than was possible even a few years ago; and the eminent English astrophysicist Jeans has estimated the age of our Sun alone

to be ten billion years—a thousand times ten thousand million!—so that the age of the whole Milky Way, of which our Sun is only an offshoot, must be considerably greater.

We have only to divide this 10 billions (a 1 with 13 noughts) by the time which occurs between the engendering of two planetary systems—that is, by 10 milliards (a 1 with 10 noughts), and we see that there must be many *thousands* of planetary systems like ours in the Milky Way alone; planetary systems which are, will be, or have been, capable of supporting organic life.

. . . . .

Then are there—to call things by their right names!—are there "human beings" on other planets?—If you will take the trouble to follow the explanation which I have just given, I believe you will feel that you cannot definitely answer "No"!

If any of you are still unconvinced that our Earth, that speck of dust in space, cannot possibly be the only planet in the universe to harbour life, I will tell you now, though I should have liked to reserve such surprises for later chapters, that there are, in the universe, *hundreds of thousands* of systems like the Milky Way which we see shining in the sky on clear moonless nights.

Are there rational beings elsewhere than on our tiny Earth? You may confidently answer "Yes"!

The days are past when it was the fashion to burn men like Giordano Bruno at the stake because they could not answer this question otherwise.

CHAPTER VI

COMETS AND METEORITES

It was one Carnival night—I forget the year; but one of the ordinary little comets was visible; quite a harmless little thing, only visible in the telescope, as a tiny luminous cloud. I was sitting in the tower of the observatory. The numerous visitors who had hastened to the observatory at the news of such a "star with a tail" had already gone; most of them disappointed. It was late in the night.

But when the full moon is in the heavens, or when there is even a comet to be seen, we have no peace at the observatory. Two visitors were announced by the night watchman: a journalist, with a friend. The popular dread of comets—prophecies of the end of the world—there was "copy" in such things; and it was just as well to see one of these calamitous objects with one's own eyes. Even as seen through the telescope the comet was not particularly exciting; still, we were all three in excellent spirits. We spoke of the dark Middle Ages; how a hen laid an egg in Rome which had on the shell a picture of a comet's tail, and how shortly afterwards the comet was actually seen in the heavens, like a threatening rod of fire; of stories of pestilences, and the death of princes, and other calamitous things, all of which, as we may read, such a comet was supposed to have foretold or produced; and lastly, of the possibility that we might once more enjoy the experience of passing through the tail of a comet as

we actually did in 1910; quite peacefully, as it happened, and without suffering the slightest inconvenience.

The two visitors took their leave. My assistant and I covered up the 8-inch Zeiss refractor for the night. We called the night watchman to light up the five flights of stairs that lead down from the observatory. We were still under the influence of our lively conversation; we had likened the great comet of 1910 to a fiery signal, and "Switch on your fiery signals"! I called to the night watchman over the telephone; and then I locked the bookcases and the doors. Unsuspectingly we went downstairs.—A slight tinkling sound aroused our attention; perhaps something was amiss in the telephone-box; we stopped and listened for a moment, and then went quietly on down the stairs. But the sound of the telephone-bell grew louder, and at last, when we reached the ground floor, what a scene awaited us, and what a surprise! Like a crucified figure, there stood the watchman, with outstretched arms, a couple of keys in one hand, and two hundred and sixty kronen—our night's takings—in the other, his face horribly distorted and white as chalk:—"Isn't it on fire"? he cried. He was utterly disconcerted, not because there was a fire in the building, as he firmly believed, but because of the abominable unconcern with which his superiors were descending the stairs! My innocent if rashly worded order to switch on the lights on the landings had been misunderstood. He had called up the fire-brigade! Mysterious signals from the fire-watcher at the old palace had set the

whole building in a ferment. A terrible din disturbed the peace of the starry night; apparently the devil himself was keeping carnival! I ran to the telephone: "Hullo! Give me the fire-station, please!"—"Hullo! Central fire-brigade speaking!"—"I want to explain that there has been a misunderstanding."—But it was too late.—"Three engines are on the way!"—We went out into the night, and my friend set off running at a furious pace.—"What's the matter—what are you doing?"—"I want to meet the fire-brigade, to tell them not to whistle"!—I felt that I must reserve all my energies for their reception, and I really had no time to laugh.

Trara!—The shrill alarm might have been the trumpet announcing the (rather brilliantly coloured) end of the world! For in the few minutes during which we were quickly descending from the observatory a truly imposing rescue-party had assembled. There were three fire-engines from the Central station; a little way behind them was another engine from another part of the city; there was a small army of police and ambulance men and what not; and at the back of all a fourth fire-engine, attended by an ominous fire-escape, from the farther side of the Danube Canal.

Here was a situation for which we felt the greatest respect! Most fortunately the chief of the fire-brigade was a man of great tact, and delightfully "understanding". And it so chanced that he was an amateur astronomer! A few formalities—two sighs of relief—and that was the end of the matter.

But who shall say, after this, that the stars exert no influence over human beings?

A comet—and by no means a large one; some talk about the "end of the world"; the "fiery signals", and then—the fire-brigade! If this was not "influence" there is no such thing!

. . . . .

If we are to believe all we read and hear, the world comes to an end about once in every five years. Very often a comet is responsible; when the "end of the world" does not come as foretold, there are always people who are sure that it is only postponed for a time.

There must, after all, be some reason why comets have always attracted such attention from people of all classes. To begin with, of course, a really large comet is a strange and beautiful spectacle. As a matter of fact, new comets are discovered every year, or old friends revisit us. But these are quite unpopular and purely "telescopic" objects. Large, brilliant comets with long, sweeping tails are very rare indeed. Since 1910, when we were favoured with two magnificent examples—the "Johannesburg comet" and "Halley's comet"—no such celestial marvel has appeared, so that the next will come as a surprise to many observers.

But there is a second reason why one cannot treat the advent of a comet with indifference. Comets are, by their very nature, mysteriously extensive objects, whose actual length is enormous; far exceeding, for example, the diameter of the Sun. Even the "head"

which contains the "nucleus", the brightest portion, is considerably larger than the Earth, and the tail may measure anything from ten to a hundred million miles in length.

The better to compare it with the Sun and Earth, we will once more resort to our "planetary scale", by which everything is reduced to one-milliardth of its actual dimensions; in other words, a metre represents a million kilometres.

The Sun, the size of a coach-wheel, is the centre of our imaginary model system; the Earth, of the bigness of a hazel-nut, revolves round it at a distance of 150 metres. And now come the comets, equipped, even on this minute scale, with tails whose length may vary from 16 to 160 metres in length. What will the little hazel-nut do when it meets with something the length of a good-sized ball-room, or perhaps as long as a cathedral? It may happen—for it has already happened—that our Earth will plunge right into the gigantic tail of such a comet.—At first sight it really would seem that this might mean the end of our little world!

. . . . .

But let us look more closely into the structure of the comet. *Coma* is a Greek word, meaning the long tresses of a woman.—To begin with, what is the head of the comet?—It may be fairly, if not very exactly, described as a heap of stones. But these stones may not be ordinary stones; they may also be lumps of metal, and especially of iron. Such "stones", when

they fly through space, are known as cosmic dust, or *meteorites*. The head, then, is a collection of meteorites, and a fairly ponderous heap, whose individual parts are not large, even according to our earthly ideas; there may perhaps be lumps as big as one's fist; and also particles which, without any reduction to a smaller scale, would be regarded even by a chemist as mere particles of powder. We shall presently see that we are actually familiar with such cometary fragments; that we can even take them into our laboratories and inform ourselves as to their chemical constitution.—But for the moment we will venture to tackle the natural history of the comet from the more difficult side. Whence do these heaps of stone and metal come? Where are they created? What is the *origin* of the comets?

. . . . .

Questions of cosmogony must always be answered with a certain reserve; sometimes it is difficult even to *ask* them. But here is a plausible suggestion. Far away in space, a few billions of miles from our own Sun, are its sister suns, the nearest fixed stars: Sirius, for example, or Altaïr in the Eagle, or Alpha of the Centaur (which in our latitudes, however, is never visible). We may assume that these suns formed themselves out of a finely divided medium, a primitive "nebular mass". "We simply divided ourselves up in space", you may imagine them telling us to-day, if they could speak, "as your earthly states are divided in your continents." But just as here on the Earth very small countries get left over, and preserve their independence, so it may

have happened in the creation of the masses of the suns out of the great universal nebula. Little clouds of nebular matter were left over, which congealed into solid bodies, into meteorites, which were uncertain whether to go on pilgrimage to Sirius or to its neighbour, our Sun. At first, perhaps, there was an equilibrium of forces—of the forces of attraction—and the merest accident was decisive. One heap of meteorites drew off in the direction of Sirius, and another in the direction of the Sun, *our* Sun; drawn at first by forces so indescribably small that our heap of stones may have taken countless thousands of years to feel sure that it was really allotted to our solar system. It was only a little dark heap of stones, which no human eye had ever seen, no human mind had ever suspected; and out of the cold, dark universe it fell towards the Sun. *Fell*—and this was the great discovery of Newton —just like an apple that strives to fall to the ground.

. . . . .

Yes: even such a wanderer through space, such a heap of meteorites, is subject to the natural laws, which were first stated by Newton. Two masses always attract one another; the heavier they are, the greater the attraction; the greater the distance between them, the less the attraction. This is the first and most important principle. And here is a second principle:

Two heavenly bodies—for example, a heavy body and a lighter one—move, in obedience to their mutual attraction, in such a way that the lighter body moves round the heavier, or each moves round the other, in

a path which is a *conic section*. The conic sections are: the circle, the ellipse, the parabola, the hyperbola.

Now let us learn by experiment what sort of curves these are. All we need for the experiment is a pocket

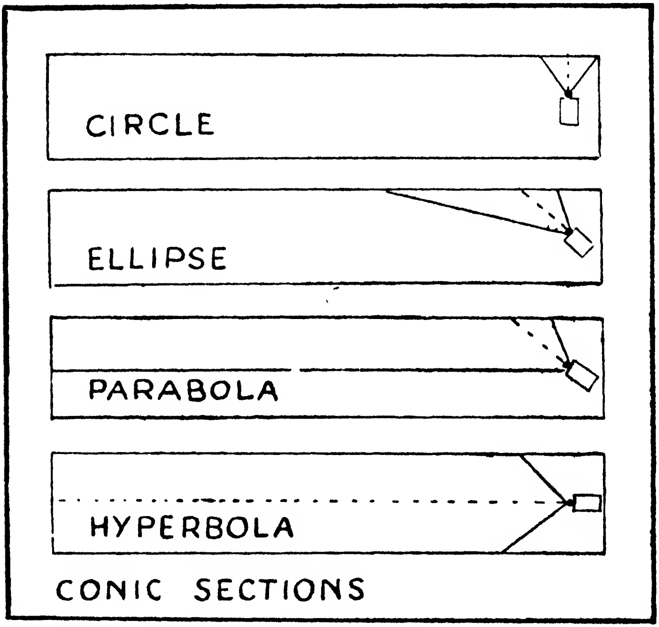

FIG. 13.—Producing Conic Sections with a Pocket Torch.

flash-lamp and a dark room with a long blank wall (Fig. 13). We will stand in the corner of the room, about a yard from the walls, so that one of the end walls of the room is on our right, and the other, farther away, on our left. We allow the beam of light, or rather the *cone* of light, to shine directly at the wall,

so that the axis of the cone of light is at right angles to the wall. The outline of the bright patch of light on the wall is then a *circle*. Now we turn the lamp sideways, and the circle becomes an *ellipse*, whose longer axis is parallel to the floor. If we turn the lamp a little farther, so that its horizontal axis—that is, the axis of the cone of light—makes a smaller angle with the wall, the ellipse becomes more and more elongated. If the wall were long enough we should see the ellipse growing more and more elongated, until we could no longer see its farther end. The ellipse finally becomes a *parabola*. We shall obtain a parabola (and this course is of especial interest to us since we are talking of comets) if we swing the axis of the lamp until the end of the ellipse of light turns the far corner of the room and moves out exactly one yard across the end wall. One side of our cone of light (the "side" of the cone is any straight line along its curved surface) is now parallel to the long wall. We have now the exact outline of a parabola.—If we now turn the lamp still a little farther the lines dividing light from shadow on the long wall will grow straighter and straighter. We have now a hyperbola.—*Why* this is so you may read in any textbook of geometry. Here I will merely remind you that the only *closed* conic sections are the circle and the ellipse.

. . . . .

Our heap of stones "falls" towards the Sun. It might, if chance so willed it, even fall straight into the Sun. But the very least disturbance gives the body a lateral

impulse, and the heap "falls" in a conic section, usually in a parabola. It rushes onwards with ever-increasing speed, and finally curves round the Sun; then, retaining the impetus and energy of its rapid movement, it swings round to the other side of the Sun, and now, moving away from the Sun, which still calls to it, and still, though with ever-decreasing power, holds it in check, it sails far away into space.—Its path was and remains parabolic.

It often happens, however, that the open parabola of a comet's path becomes an ellipse; another conic section, which is much more strongly curved, and is closed. We know this without a doubt; but the calculation of the "perturbations" by which the transformation is effected is one of the most difficult branches of astronomical science.

. . . . .

The Sun is the ruler of the realm of the planets, and, as we have just seen, of the comets as well; but he has competitors. Jupiter, of course, is no pretender to the throne; with his weight, more than a thousand times less than that of the Sun, this would be a hopeless ambition. Yet what the Sun can do Jupiter can do, though in a less degree. If the Sun can attract a heap of meteorites, so can Jupiter, and in the course of events it has happened that Jupiter has compelled comets which had set their course for the Sun, with the intention of quietly completing their parabolic path, to do reverence to him also, and to regard him as a second "focus". In short, Jupiter has transformed

the originally parabolic path of the comet into a closed elliptical orbit. In the course of time he has contrived to collect a whole family of comets. These captured visitors are now naturalized members of the solar system, and belong to it just as much as do the planets; and the eminent Danish astronomer, Elis Strömgren, by observing the elliptical paths followed by a number of comets on their successive appearances, and by investigating all the perturbations which affected them in their earlier phases, was able to prove that *all* the comets had their origin in remoter space, far removed from the inner planetary system.

. . . . .

Saturn too is responsible for a family of comets, and Uranus also; and even Neptune is not without influence in this connection. Indeed, it has occasionally happened that *two* interfering planets have competed for a comet, and tugged it in opposite directions, until at last it has actually been torn in two before the eyes of the astronomers. Such a wanderer through space will be drawn now hither, now thither by all such bodies as have a sufficient mass, and therefore a sufficient power of attraction, and its orbit will sometimes be greatly distorted.

. . . . .

A comet comes from an inconceivable distance. It so chances that it meets the planet Neptune; it respectfully turns aside, and then encounters Saturn, and then Jupiter.—It seems impossible that anyone should

succeed in describing the complicated path of such a roving body in a sentence; yet the Göttingen scientist, Wiechert, solved the problem in a whimsical conceit: "Every body in space moves in such a way as *to experience as much as possible*."—I am not sure that we might not say the same, if not of everybody on earth, yet of a good many people!

. . . . .

There are, then, comets with parabolic paths. These belong to our solar system only in so far as the focus of their paths, even though they sweep away into space, lies in the Sun. They come, and go, and are never seen again. Three-fourths of all recorded comets belong to this group, if we include those which the astronomers class as comets with hyperbolic orbits. For their hyperbolas are so nearly parabolas that one does not place them in a separate category. The remaining one-fourth of the comets follow elliptical orbits, which are, for the most part, from fifty to two thousand times as long (measured along the axis) as the distance from the Earth to the Sun. Some of these very long ellipses, again, approximate to parabolas, so that we may say that the parabolic orbit is the first characteristic of a comet.

. . . . .

So much for the paths of the comets.—While our dark heap of meteorites is still far away in space—it is difficult to say where the limit lies, but perhaps at 60 million miles or so—it is still quite invisible to the

human eye and to the telescope. "As many fishes as are in the sea, so numerous in space are the comets", said Kepler; but we cannot see these celestial fish.—Only when the shoal of meteorites has come within a certain distance of the Sun or the Earth is it possible to detect it—at first, as a rule, only by chance, and by means of an unsuspecting photographic plate, and then, later on, through the telescope; a little cloud of light, like the comet that turned out the fire-brigade.

This little cloud is already shining in the sunlight, since the meteorites of which it is composed are rapidly approaching the central star. Then they begin to grow hot. The gases contained in them expand, and split the stones asunder. The spectroscope enables us to demonstrate that some of the light received is emitted and not merely reflected. Their spectrum shows the presence, among other substances, of sodium, hydrocarbons, and cyanide compounds. These substances are incandescent with heat, or by reason of high electrical tension; so far we are not quite sure which is the case. But this at least is certain: that as the comet draws closer and closer to the blazing Sun, some proportion of its substance is exploded into the smallest conceivable fragments; in a word, it falls into dust.

The whole mass of material—at first a comet-head without a tail—is attracted by the Sun; the finest particle no less than the heavier masses. And now a sort of envelope or hood—the *coma*—develops round the head, and this cloudy mass sinks down towards the Sun. But after a while a singular thing occurs. The coma changes its direction; it swings round, flying

directly away from the Sun, until it attains an enormous length; and so the tail is formed. This tail is always turned away from the Sun. If the Sun, below the horizon, is directly underneath the head of the comet, the tail points directly upwards.—This singular behaviour of the tail has long been known. Kepler, even as early as the seventeenth century, asserted that the mass of the Sun must exert a repulsive force on the material of the tail; but this statement was merely a description of what was visible to the eyes; it was not by any means an explanation of the phenomenon.

. . . . .

It was reserved for the modern physicist to solve the mystery. The Sun attracts all bodies, great and small, but when matter which is undergoing progressive pulverization attains a certain degree of ultra-microscopic fineness it is repelled by the light of the Sun. This curious property of light has been demonstrated in the laboratory; on very finely divided matter it exerts, under certain conditions, a force of repulsion. This phenomenon is known as *light-pressure* or *radiation-pressure*, and the Swedish scientist Arrhenius was perhaps the first to relate this physical discovery to the physics of the comet. Bredichin, a Russian astronomer, has endeavoured to explain why in certain cases the tail of a comet appears to be divided or duplicated. He shows that the different constituents of the matter which forms the tail—for example, the light hydrogen, and then the elements and compounds of greater

density, and finally the heavy metallic vapours—must be differently affected by the repulsive force of light. It is true that he assumes the repulsion to be a purely electrical phenomenon, but there is no reason why we should not interpret it as a phenomenon of light-pressure. Whether the tail thus repelled by the light of the Sun shines only by reflected sunlight, or whether other internal energies are at work, is still in question. It is quite conceivable that the light is both reflected and emitted.

. . . . .

The longest tail, perhaps, was that of the comet of 1843. Its length was reckoned at no less than 155 million miles—one and two-thirds times the distance between the Earth and the Sun. On our planetary scale of 1 : 1,000,000,000 (the Earth, you remember, being the size of a hazel-nut) this would be nearly one-sixth of a mile. A terrifying apparition! Fortunately, its density was so small that it was harmless. We know that the tail consists largely of particles so fine that they would be invisible even in the most powerful microscope. And even the head is not dangerous. It is, indeed, a heap of solid stones, and the possibility that it might fall on the Earth is not wholly to be ignored. As a matter of fact, such showers of stones have fallen on the Earth, but the Earth still goes its way.

"Donati's comet" also was a magnificent spectacle. (A comet, as a rule, is named after its discoverer.) Donati first observed the comet which bears his name

on June 2, 1858; it then appeared in the telescope as a faint nebular mass. Not until three months later was it visible to the naked eye; but after this it gradually developed into the most imposing comet of the century. On October 10th it was at its brightest, shining resplendently not far from the Plough; it then had a strongly curved, fan-shaped tail, and it remained visible until March of the following year. The time of its revolution round the Sun was calculated to be almost 2,000 years, so that this comet must have paid its last visit to the Sun and the Earth in the days of Hipparchus, the great Greek astronomer.—The year 1882 was distinguished by the great "September comet".

1910 was again a "comet-year". The January or "Johannesburg" comet did not attract much attention; the second, which was Halley's comet, was much more conspicuous, and in May the Earth passed through its tail.—It was a clear night, and we sat up, full of interest and enthusiasm, but we noted nothing in particular. In Paris balloons were sent up on the critical night; the aeronauts opened exhausted flasks, and then hermetically sealed them; the air was carefully analysed, but with negative results. Those who prophesied the "end of the world", and the flooding of the atmosphere with poisonous gases from the comet's tail, were disappointed.

Halley's comet took its name from a pupil of Newton's. It made its appearance in 1682. Halley proceeded to calculate its orbit by the methods which he had learned from his master. He prophesied that it

would return in 1759. He himself was not alive to see his calculations justified. Clairaut revised his calculations, carefully allowing for the perturbing influences of Jupiter and Saturn. Only a month before the calculated time—truly a small discrepancy in a period of more than seventy-five years—the comet was seen approaching the Sun. This accuracy is indeed surprising, if we reflect that between its two appearances the comet had sailed away far beyond the orbit of Neptune.—In 1835 it appeared within two or three days of the calculated time. In 1910, the year of its latest appearance, the calculation was correct to within a single day.—I hope my younger readers may live to see it return in 1985.

. . . . .

In conclusion, I will tell you of just one more interesting comet. It was not a very well-known comet, but it proved that our theory of the structure of these heavenly bodies was actually correct. I am speaking of "Biela's comet", which was "discovered" in 1826 by an amateur, an Austrian officer; and at the time of its "discovery" no one had any suspicion that the comets of 1772 and 1805 were simply earlier appearances of this same comet. Its period appeared now to be only six to seven years; and in 1832 and 1839 it returned according to programme. But in 1845 it was seen that the comet was torn in two, and the two portions were moving quietly side by side; one of them like a phantom hand holding a stick of phosphorus, and the other a tiny luminous cloud. By the time of their next visit, in 1852, the two

portions were more widely separated; they were at first some 180,000 miles apart, but by 1852 this distance had increased to 1½ million miles. But something even more surprising was to follow. At the next appointed time, indeed, the comet was not visible; nor yet at the next after that. The astronomers were beginning to believe that it was lost to the solar system, when something very strange occurred. Just at the time when the comet was due—in 1872—a great number of magnificent shooting stars appeared in the region of the heavens from which the comet, which was not yet quite definitely given up for lost, should have made its appearance. Seven years later, in 1885, this dense swarm of meteorites reappeared. It was now clear beyond a doubt that the comet had been divided not merely into two parts, but into thousands of fragments, which as shooting stars provided a magnificent spectacle. They came rushing out of the constellation of Andromeda, and were consequently known as the *Andromedids.* They still make their appearance, though more sparingly, at the end of November. Their orbit is identical with the orbit of Biela's comet. The connection between comets and meteorites is confirmed, and you will now understand why I described the comet's head as a heap of stones or meteorites.

When we see a bright and beautiful shooting star we are supposed to wish for something particularly desirable. It is an old custom, and the most matter-of-fact scientist cannot deny that the wish *may* be fulfilled!

We commonly speak of *meteors*, and call them shooting stars only when they are small. They often occur in swarms. They are known as *fire-balls* or *bolides* if they are quite exceptionally brilliant. Such meteors —which almost invariably occur singly—sometimes explode, and terrify nervous observers; in rare instances they even fall to earth.—All meteors are fragments of other worlds—stones, lumps of metal, cosmic particles wandering through space in infinite abundance. The thing itself is a *meteorite*; the visible shooting star or fire-ball is called a *meteor*. Meteorites do not always follow the paths of comets, but fly wandering through space, though they are always directed by the attractive force of gravity. We cannot see them; they do not shine with a light of their own; but sometimes, at midnight, in that region of the sky which is opposite the Sun, the observer may perceive a little patch of faint luminosity on the black background of the heavens. This *Gegenschein* or "counterglow" is believed to be the reflection of the Sun—the light reflected by thousands of millions of these dark little wandering bodies.

When such a meteorite rushes into the atmosphere of the Earth it compresses the air in front of it, "strikes itself", so to speak, on this cushion of dense air, and ignites. It burns for a few seconds only; and while it burns it is a meteor. Most meteors burn to dust, which floats away and is dispersed. Only a few very refractory meteorites fall to earth as "meteoric stones". In the larger museums one can often see gigantic specimens of such stones. Two very large meteorites are those

which fell at Youngadin in Australia and at Tucumana in Mexico. The first of these weighs about 1,800 lbs., the second 15 tons.

. . . . .

Fire-balls, or large meteors, are not so rare as people assume, and any observer who has watched the sky for years can tell you something about them. Sometimes a few fire-balls will fly across the sky in long, parallel straight lines; sometimes the head of a meteor —the actual fire-ball—will split into three parts, each with coloured edges, which pursue one another across the heavens, leaving a long, broken trail of fire behind them; at other times a meteor will remain visible for as long as sixty or seventy seconds.—Anyone who has seen such a celestial display will remember it all his life. But few people know, even to-day, that when they chance to observe such a phenomenon they should at once advise an astronomical observatory.—And why? —Well, it is possible, by means of the different reports received—the more numerous they are the better—to ascertain the height at which the meteor ignited, and thereby it is possible to solve the very important question: how high does the atmosphere of the Earth extend? But this, from the astronomical point of view, is a comparatively unimportant problem; what the astronomer wishes to know is: from what distances do these fire-balls come, and from what regions of space? Niessl in Vienna and Hoffmeister in Sonneberg have clearly demonstrated that the fire-balls—that is, the large meteors—almost without exception come to

us from regions far outside the solar system.—It is highly desirable that more material, in the form of fresh observations, should be collected, as it may assist in the definite solution of many minor problems. So, if you have the good fortune to see a large meteor, you should at once note down the details of your observation as accurately as possible, and forward them to the proper quarter.

. . . . .

To do this you need no telescope, no special knowledge: only good will and a sheet of notepaper.

Do not forget to begin by stating who you are and where you live, so that the astronomer who calculates the path followed by the meteor can ask you for further details if your report should be of interest.

Secondly, give the date of the observation—the day, month, and year; for it sometimes happens that reports cannot be utilized at the moment. You will of course give the time of your observation, if possible to a minute, though this is not so important as you might think, for if even three out of a hundred observers have noted the time correctly that will suffice.

And thirdly, we will assume that a meteor explodes at a certain height. Now, one observer, who is directly underneath the meteor, will see it burst at the zenith. A second observer, some 50 miles to the south of the first, will report that he saw the meteor at an altitude of 45°. What can we deduce from this? A simple sketch will show us at once that the meteor burst at

a height of 50 miles above the first observer. The greater the number of the reports received, the more reliable is the calculated result. If, in addition to the point where the meteor burst or was extinguished, we record the point where it first became visible, and estimate how many seconds it took to cover the distance between these points, the astronomer can readily calculate the velocity of the fire-ball. It comes to this: we have to define the beginning and the end of the meteor's path. If we are more or less at home among the stars, we can give these positions with reference to the constellations, or the Moon.—"The meteor ran from a point about six times the breadth of the full Moon to the left of the Pole-star to a point just under Vega."—If it is not possible to describe the path of the meteor in relation to the stars, we may refer to the points of the compass. "The meteor appeared exactly in the West, and its point of extinction was due North; it moved horizontally half-way between the horizon and the zenith." The easiest and often the most accurate method of description is to refer the path of the meteor to terrestrial objects. You can make a sketch of the landscape to the best of your ability, and say that the meteor appeared so many inches or centimetres—measured at arm's length—above the church, moving from A to B, and that its path ended above the *n*th tree of the avenue. If the position of the observer is known—and it should, if possible, be marked on a plan or map of the neighbourhood—together with the time of the observation, it is possible, should the meteor be of sufficient interest, to check the

data subsequently on the spot, when the astronomical position of the points described can be ascertained.

Fourthly, we should describe the shape of the gliding "head" of the meteor: whether it was round or pear-shaped; if the head exploded, and what colours it exhibited; whether a tail or trail was visible; and how bright the head was—whether it was as bright as a star of the first magnitude, or as bright as Venus at her most brilliant, or even brighter.

And fifthly, for how many seconds was it visible? You are always taken by surprise; there is no time to look at your watch. As a rule the time is over-estimated. The best thing you can do, when writing down the details of your observation, is to lay your watch on the table, and, while gazing at the second-hand, mentally to recapitulate the whole phenomenon.

Sixthly and lastly, it is very desirable to add supplementary remarks; whether the meteor was seen by others besides yourself; whether any detonation was audible; what the weather was like, whether the sky was clear or clouded, and so forth.

. . . . .

Science has often been enriched by the reports of laymen and amateurs. I myself have been receiving reports of meteors for more than twenty years, and in response to the usual brief appeal in the press I have often received more than five hundred records of a single phenomenon, which enabled me to calculate the path of the meteor; and often enough among all these observers there was not a single astronomer.

Here is a field in which the amateur has ample opportunity to co-operate in the work of our observatories.

The calculated results are often of great interest. For example, Niessl was able to calculate that the meteor of January 13, 1917, shone over Bosnia at a height of no less than 350 miles, and then passed right across Hungary, burning itself out over Bielitz-Biala, after a trajectory of more than 500 miles. His calculations tell us that even at this enormous height the Earth's atmosphere must have had sufficient density to heat to incandescence a body with the chill of space upon it.

To-day we are able to say, if we know the velocity of a meteor, whether it belonged to the solar system: that is, whether, like the planets, and such comets as follow elliptical paths, it was moving round the Sun, within the field of solar gravitation, or whether, coming out of endless space, it merely chanced to collide with the atmospheric envelope of our Earth. If meteors attain a speed of more than 26 miles per second, we may assume that their origin is far outside the solar system; that they have come to us, so to speak, from another sun. We may picture whole streams of meteors flying in almost straight lines through our solar system —or rather, attempting to fly through it, but happening to collide with our Earth. That the large meteors, the true "fire-balls", do actually come to us from outer space has been demonstrated beyond a doubt by Niessl of Vienna.

. . . . .

But what of the smaller meteors, the ordinary shooting

stars?—In the case of the shooting stars of the swarm known as the Bielids, we know something of their origin. They constitute rings of cosmic dust; they are the remnants of a former comet. When the orbit of the Earth intersects this swarm, the atmospheric envelope of our planet receives and deals with the flying fragments. Besides the Bielids, whose relation to a comet is proved beyond a doubt, there are several other such recurrent cometary swarms, one of which, the Perseids, recurs every year; and although the frequency of the shooting stars in this swarm varies from year to year, they are always numerous enough to repay the observer who will watch for them on the nights of August 9th and 13th.—A second swarm, the Leonids, is interesting for historical reasons, though less spectacular than it used to be.

In August 1907 I was able to observe the Perseids on three successive nights; the first night with a little company of holiday-makers; the second night with two friends, one of whom recorded our observations, while the other, who had come from some distance in order to assist us, fell into a comfortable sleep a little after midnight. This, however, did not upset our programme, for two observers were quite enough. On the third night I was alone. On the night of August 9th, 61 meteors were seen; on the night of the 10th, 137; on the night of the 11th, 225; in all, 423; and these were not merely recorded, but were marked on a star-map. The result was just what we expected; the great majority of the meteor-tracks, if one produced them backwards far enough, converged upon a certain point,

not far from the star Gamma in the constellation of Perseus.

Such a point of radiation is known to the astronomers as a *radiant.* It seems as though the shooting stars were discharged in all directions from this point of the firmament. But it only seems so; in reality the meteorites fall out of space in parallel lines, just as the individual railway-tracks emerging from a large railway-station run parallel to one another, although to us, if we are looking along the track towards the station, they seem to diverge like the spokes of a wheel. The "radiation" of the railway-tracks, like that of the Perseids, is a mere effect of perspective.

But how comes it that the Perseids fly in parallel lines?—Well, they are, like the Bielids, the remnants of a comet, which in 1862 was visible as a comet, and had a periodicity of well over one hundred years. It revolved in a long ellipse round the Sun, but it was already decrepit with age, and it somehow dissolved into fragments, in such a manner that these form a closed elliptical ring, whose further extremity lies as far beyond the orbit of Neptune as the distance from the Sun to the orbit of Uranus.

It so happens that the orbit of the Earth intersects this ring of meteorites, and every August, on the dates I have mentioned, the Earth dashes once more through the swarm, igniting its particles, so that they fall like "the fiery tears of St. Lawrence". Since the ring of meteorites is not of uniform density, the number of meteors varies from year to year. We are not yet able to forecast the "frequency" of the meteors, so that you

will be doing useful work if you include the observation of the Perseids in your holiday programme. It is enough merely to record the number of shooting stars observed in the neighbourhood of Perseus—from 10·0 to 11·0, from 11·0 to 12·0, from 12·0 to 1·0, and so on, until the dawn. Anyone can do this, even if Perseus is the only constellation that he knows; and if he does not know even Perseus, he can get someone to point it out to him.

The history of another swarm, that of the Leonids, so called because the meteors—about the middle of November—radiate from the constellation of the Lion, begins—apart from mere records of their appearance, which go back to the days of the Arab astronomers—in the year 1799. In that year Alexander von Humboldt was travelling in the Andes, and wrote a most impressive description of a dense shower of meteors which proceeded from the constellation of the Lion. Thirty-four years later Olbers observed a similar swarm, and ventured to assert that it was identical with the swarm of 1799, and having decided that its orbital period was thirty-three years, he forecast its next appearance in 1866. In 1866 there was actually a very fine display of meteors, and it was then obvious that the Leonids, like the comets, travel round the Sun in a closed orbit. It was found that this orbit was an ellipse whose longer axis extended beyond the orbit of Uranus. The astronomers, naturally enough, anticipated a return of the swarm in the year 1899. Elaborate preparations were made for observing it—and the observers were completely disappointed.—The explanation of the non-

appearance of the swarm was simple enough. Jupiter, as we have seen, is an interfering sort of planet. He had pulled the swarm aside with such effect that it will, in all probability, never again collide with our atmosphere.

There are in all about half a dozen such periodic swarms of meteorites, which, like the Perseids and the Leonids, are undoubtedly of cometary origin.

We know this from comparing their orbits and their

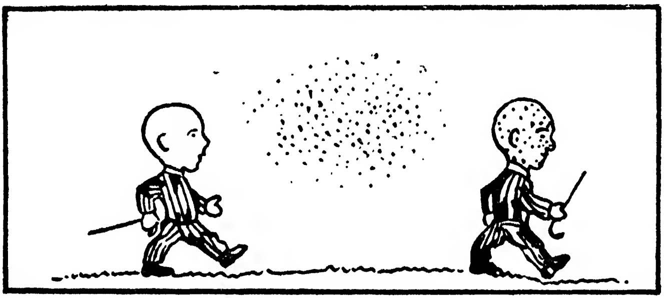

FIG. 14.—Illustrating a swarm of Shooting Stars of comparatively low velocity relatively to the Earth.

periods with those of the corresponding comets. Much is learned by ascertaining the velocity of the meteors of different swarms. The Perseids ignite at an average height of 70 miles, and burn out at a height of about 56 miles. If two observers at some distance from one another note the points of ignition and extinction of the same meteor, and estimate the time it has taken to travel from point to point, they are able to determine the velocity of the individual meteors. This, however, is a very exacting task; in particular, it is by no means

easy to identify the individual meteors by means of these so-called simultaneous observations. There is, however, a much simpler method, which we owe, in the first place, to Hoffmeister. By this method we ascertain the velocity of the meteors merely from their numbers. This sounds incredible; but it is, as you will see, comparatively simple.

. . . . .

Here are two little pictures (Figs. 14 and 15). In the

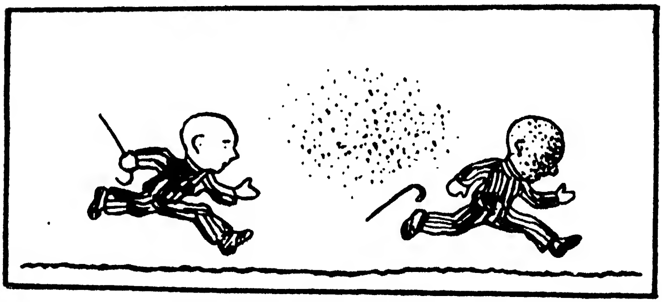

FIG. 15.—Illustrating a swarm of Shooting Stars of comparatively high velocity relatively to the Earth.

middle of the first picture is a swarm of midges. A little man, with a round head, as round as the Earth, hurries through the swarm. We will imagine that he has anointed his whole face and head with some fly-catching paste or ointment; for what will one not do in the cause of science?—After the man has passed through the swarm his shaven head is speckled with black midges, but, as we can plainly see, the face is covered much more thickly than the back of the head.—In the second picture, in which our round-

headed little man rushes through the cloud of midges at a much greater speed, the difference between the numbers of midges adhering respectively to the face and to the back of the head is much more conspicuous. —We can even conceive that it must be possible to calculate the *speed* of the runner from the differing "density" of the midges on the face and on the back of the head.

Instead of the cloud of midges, we will consider a swarm of meteors, whose frequency, *x*, is still unknown. In the place of the bald head of the running man we have now the round Earth. But what are we to understand by the "face" of the Earth?—I will explain. The Earth circles round the Sun.—Now draw, at the top of a sheet of paper, the Sun; and beneath it the Earth, with its sunny side upwards. The Earth, in order to describe a circle round the Sun as centre, moves towards the right; but we are concerned only with the little sector of the circle which the Earth will cover in the course of a night. We may compare our Earth with the little man in the picture, whose face is turned to the right. Now, if we consider that the Earth rotates on its axis in the same direction as that in which it revolves round the Sun—both movements being "anti-clockwise"—we shall realize that in those regions which are to the right of the Earth, on its "face", it is morning, or nearly dawn; but on the other side of the Earth, at the "back of its head", it is evening, or early night. What must we do, then? Just this: we must simply *count* the shooting stars, all night long; for it must be possible, from the difference in the numbers observed

after sunset and before dawn, to determine the speed of the shooting stars. You have only to *count* the meteors, nothing more; and by means of such simple statistics the astronomers can ascertain the velocity of the meteors.—And if we know the velocity of a heavenly body in the neighbourhood of the Earth, we can determine whether this body is moving in a circle, an ellipse, a parabola or a hyperbola.—From the form of its orbit we can tell whether a swarm of meteorites belongs to our solar system or comes to us from interstellar space. Such calculations have been made, and they tell us that apart from the very few purely cometary swarms already mentioned, which are to be regarded as belonging to our solar system, by far the greater number of the smaller shooting stars, as well as all the large single meteors, must come out of interstellar space, perhaps from the "spheres of influence" of other suns.

CHAPTER VII

THE MARVELS OF THE MILKY WAY

"How many stars are there in the sky?"—Well, I can tell you how many we see:

There are

14	stars of the 1st magnitude.
39	stars of the 1st and 2nd inclusive.
105	stars of the 1st, 2nd and 3rd inclusive.
445	stars of the 1st, 2nd, 3rd and 4th inclusive.
1,460	stars of the 1st, 2nd, 3rd, 4th and 5th inclusive.
4,720	stars of the 1st, 2nd, 3rd, 4th, 5th and 6th inclusive.

Of stars visible to a very keen eye—the sixth magnitude being the limit of visibility—there are thus, in round numbers, about 5,000 stars. These numbers, remember, refer to the whole heavens; that is, they include that part of the firmament which is not visible in our latitudes; so, since we can have only one-half of the heavens above the horizon, we can see only about 2,500 at any one time; the other 2,500 are hidden by the Earth. And even when the horizon is unobstructed, those stars that are near the horizon are usually veiled in mist. For this low-lying region of the heavens we must subtract a good fifth of the stars theoretically visible, which leaves us only 2,000 which we can see with the naked eye.

These figures are correct only for those who enjoy really excellent sight, or whose eyes are well trained in observation. Many of us have to be content with stars of the fourth, and most of us with stars of the

fifth magnitude. If we accept these limits our figures are considerably modified; we have, for the whole of the heavens, 1,500 stars; and since only half of these can be above the horizon, this figure must be reduced to 750; and if from these 750 stars we deduct one-fifth as practically invisible, we have only 600 left.

. . . . .

"How many stars are there in the sky?"

It doesn't sound at all "astronomical"—only 600! And yet the figure is correct. I do not tell you this in order to diminish the somewhat helpless feeling which may overcome you on looking up at the heavens and thinking of the inconceivable numbers of the stars in space, and I would not deprive you of an atom of that reverence which is felt by the true lover of astronomy; but I do wish to free the beginner from the discouragement with which he sometimes approaches the study of the stars. I have heard people say that they "felt as though the enormous numbers of stars in the sky would drive them crazy"; and in order to give my readers confidence I will put before them a simple and concrete comparison.

Take a piece of "squared" paper; one of those sheets of paper which are divided into squares of 1 centimetre, which in turn are divided into millimetres. Now cut out an oblong piece, 2 centimetres in width and 3 in length, and in each square millimetre of this rectangle pierce a hole with a needle. If you hold this piece of perforated paper up to the light, you will see just as many points of light as there are visible stars in a

normal sky. This comparison will assure us that it is by no means impossible to know "all the stars" in the course of time. I am not suggesting that you ought to know the name of every star—as a matter of fact only a few have names of their own—but you will be able to say that such or such a group of stars belongs to this or that part of this or that constellation.

And here is another example which will show you

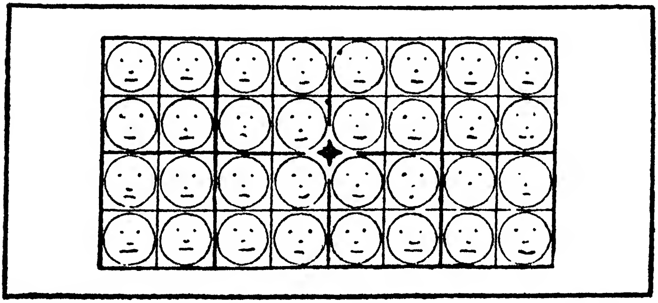

Fig. 16.—In eight square Degrees of the Heavens the Eye perceives only one Star.

how few the "myriad stars" really are. The rectangle shown in Fig. 16, with its 32 full moons (the disc of the moon, as we know, is just half a degree in diameter), represents an area of 8 square degrees. And in each such area of the firmament there is, on the average, only *one* star visible to the naked eye!

. . . . .

Through the telescope, of course, we see a much greater number of stars; the larger the telescope, the more numerous the stars. Even the ordinary opera-

glass is a great improvement on the naked eye. A telescope with a 4-inch objective will show stars to the ninth or tenth magnitude. These so-called "magnitudes" have no relation to the actual diameters of the stars. They represent only the *apparent* brightness of the stars, and to-day the astronomers speak even of stars of the twenty-first magnitude; these, as a matter of fact, are points of light so extremely faint that no eye has ever seen them, even with the aid of the most powerful telescope; nor, so far as we can tell, will it ever see them. But a photographic plate, exposed in the field of a telescope for many hours at a time, perhaps on several nights in succession, will collect and add up the almost infinitely faint rays of light proceeding from the invisible stars until they are at last reproduced as microscopic points on the sensitive coating of the plate.

In principle, then, it is possible to number all the stars in the heavens, down to the twenty-first magnitude; but the number of telescopic stars is so enormous that we could not count them one by one, as though we were counting pence or shillings. We can only estimate their number, much as you might estimate the number of letters in this book. You would count the letters in one line, or perhaps in several lines, and take the average, and you would multiply this by the number of lines in a page, and then by the number of pages. To count the stars, of course, is not so easy as counting letters. The letters in a book are, on the whole, evenly distributed over the pages, but a single glance at the heavens will convince you that the stars are by no

means evenly distributed. In some parts of the sky they are crowded close together, while other parts are perfectly blank; and if we sweep the heavens with a telescope we shall find that certain areas have little or nothing to show us, while elsewhere one is astonished by the blaze of the innumerable stars which are crowded together in the field of the telescope—particularly, of course, in the region of the Milky Way.

. . . . .

The old Mexicans used to call the Milky Way "the white sister of the many-hued rainbow". It is possible to describe a circle round the heavens which will follow pretty closely the line of this "street of stars", which is, of course, in many places very broad and irregularly formed. The line thus drawn through the Milky Way or Galaxy (from the Greek *galaxis*) is known as the *galactic equator.* It is only approximately a "great circle", for the Earth lies a little way outside the plane of the galactic equator—that is, the plane of the Milky Way. The diagram reproduced in Fig. 11 shows us in which constellations the Milky Way, M, the astronomical equator, E, and the zodiacal line or ecliptic, Z, intersect one another. The Milky Way intersects the equator in Aquila and Monoceros.—This last inconspicuous constellation lies between Sirius and Procyon, and is not included in our star-maps on pp. 26–27. But in this region the Milky Way is particularly beautiful.—The constellations of Gemini and Sagittarius are likewise common to the Milky Way and the ecliptic.—Those who live or take

their holidays in mountain districts will know what I mean when I say that just here, in Sagittarius, the Milky Way has an absolutely plastic and tangible appearance; and certain outlying parts of it have a metallic lustre.

. . . . .

Herschel was the first to undertake a regular "gauging" of the stars, or rather of the heavens, by systematic random tests. From the number of stars which he found in different small areas of the heavens he deduced the distribution and the total number of all the stars in the whole firmament. His purpose was an ambitious one; he wished to ascertain the structure of the whole starry universe. He knew that the Milky Way was a plastic structure, a "star-cloud", and that the solar system was situated near its centre. Even the stars which lay apparently outside its silvery track were supposed none the less to belong to the Milky Way, while the brilliance of the Milky Way, and the exceptional density of the stars in many areas, was supposed to be explained by the fact that in these regions one saw more stars "behind one another"; in other words, that in these regions we were looking *farther* into space than elsewhere.

Herschel made two assumptions. Firstly, the stars were supposed, on a rough average, to be all of equal brilliance, so that those which appeared to be larger were really nearer, while the fainter stars were more remote. Secondly, that the stars were equally distributed throughout the whole of space. Both assumptions

were merely working hypotheses. It was not only permissible to begin with these hypotheses; there was simply no other basis for even a provisional solution of the problem.

The image which Herschel finally formed of the structure of the Milky Way may be described as follows: The Sun (Fig. 17) lies a little to one side of the centre of the great cloud of stars. This cloud is flattened. If we look at right angles to the direction of its greatest extension, the only stars we see are comparatively near; the bright, milky background is

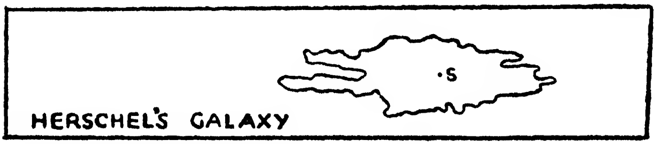

FIG. 17.—Outline of Herschel's Galaxy (S=the Sun).

absent. If we look in the direction of its greatest extension, we receive the impression of a silvery band of light. The Milky Way shines most brilliantly in Sagittarius, because in this direction our star-cloud has its greatest extension. The division in the neighbourhood of Cygnus corresponds with a twofold projection of the starry masses into outer space.—Herschel attempted to estimate the dimensions of the galaxy; and this at a time when the astronomers did not know the distance of a single star—excepting, of course, the Sun; truly a nebulous undertaking!

Herschel died in 1822. Not until sixteen years later did Bessel succeed in determining the distance of a

fixed star. This star was 61 Cygni; a star which is just perceptible to the naked eye, and an interesting object in the telescope, since it is seen to consist of two "components", two stars of the sixth magnitude.—The distance calculated by Bessel was ten and a half light-years.

. . . .

Not everyone has an equal respect for "measurements of distance in space". There are many people who will persist in declaring that a meteor has fallen into their neighbour's barn; they will tell you that they *saw* it fall, though as a matter of fact it never came within miles of the Earth. I remember one delightful incident of this kind. A night watchman in the service of the railway arrived all sooty and breathless, having come straight from the cleaning-shed, and announced that a meteor had burst *exactly* 6 miles away; he knew that, he said, "because he could see 6 miles, but no farther".

The measurement of heights and distances is not quite so simple as this.—In the chapter on the Moon I told you that the distance of our satellite is measured, at least in principle, just as we measure the height of a tower: by means of a triangle, whose base is laid out on the ground; we then measure the angle which the top of the tower subtends from either end of the base-line. It would seem, at first sight, that it ought to be possible to apply this same method to measuring the distance of the fixed stars; but these are so distant that the longest base-line that we could mark off on

the surface of the Earth would be too short to give good results. The reason is simple: even the whole diameter of the Earth is relatively so small compared with the enormous distance of a star that we should not obtain anything that we could really call a triangle. The lines of vision joining any two points of the Earth's surface to a given star would be, practically speaking, parallel to one another; for "two lines are parallel to one another if they intersect one another at a point infinitely remote".

The astronomers, however, were by no means at a loss. Even in the days of Copernicus it was suggested that this "church-tower method"—the trigonometrical method—might be applied to measuring the distance of a star, provided one took for base not a line on the surface of the little Earth, but the whole 186,000,000 miles of the diameter of the Earth's orbit. It ought to be possible to obtain a sort of perspective view of the stars. For if in summer, when the Earth, so to speak, is on the left of the Sun (though really, of course, there is no "right" and "left" in space), we see a star in a given direction, then in winter, when the Earth is on the right of the Sun, and hundreds of millions of miles from its summer position, we ought to see the star in a different position in space.

The theory is correct, but it was centuries before it was first applied with success by Bessel. To-day we have whole lists of stars whose distances have been determined by the trigonometrical method. These are, for the most part, relatively "near" stars. The overwhelming majority of stars defy all attempts to deter-

mine a seasonal displacement or *parallax* by which we might deduce their distance; to say nothing of the fainter and remoter stars of the Milky Way.

. . . . .

Taken in bulk, however, such discrepancies cancel one another by the "law of large numbers". Since in the case of the brighter stars of the various magnitudes it was possible to determine, by trigonometrical methods, an *average* distance, it was possible, in principle, to deduce a law of the relation between the decrease of the brilliance or apparent "magnitude" of stars and their average distance. Needless to say, such calculations must be made with the greatest caution, and are possible only to the expert mathematician.

In this way a sort of *statistical method* of determining the distance of stars was devised, which was based on the trigonometrical distance of the brighter stars, and which had an eminently practical aspect, since by the aid of photographic plates it was possible to estimate the distance of an enormous number of stars, and even of whole stretches of the Milky Way. By this method Seeliger of Munich was able not only to attack Herschel's problem from another side, but was able to estimate not merely the external form, but also the dimensions of the galactic complex.

. . . . .

But Seeliger too had to proceed at first from the only possible postulate; that, taking the whole universe,

the actual brilliance of the stars—the candle-power, so to speak—was the same for all stars. The very great differences which actually exist must be cancelled out by the enormous numbers with which this statistical method has to deal. On the other hand, Seeliger, unlike Herschel, rejected the assumption of an equable distribution of the stars of the Milky Way in space, and allowed the statistics to speak for themselves.

If in the whole region of the Milky Way the stars were equally distributed, the numbers of the stars of the different magnitudes would increase in inverse proportion to their brightness, in accordance with a fixed law which can readily be formulated and applied. In this case, for example, all the stars down to the third magnitude would be contained within a certain sphere, whose dimensions can easily be calculated; all the stars between the third and the fourth magnitude would be contained in a still larger sphere, and the numbers of the stars would increase from sphere to sphere in accordance with the simple rule of spherical volumes.

The diagram shown in Fig. 18 is intended to illustrate the method of dealing with series of numbers. The figures in the first column represent stellar magnitudes; for example, 9·5 represents a magnitude between the 9th and the 10th. The 7 dots opposite the figure 10·5 indicate that the number of stars down to the 10·5 magnitude inclusive is so great that it must be written with 7 figures: that is, it is of the order of so many millions. The black dots represent merely figures, and for our present purpose it does not interest us to

know whether each of these dots means a 1, a 5, a 9, or some other number. The eight points in the last line indicate that of stars down to the 15·5 magnitude

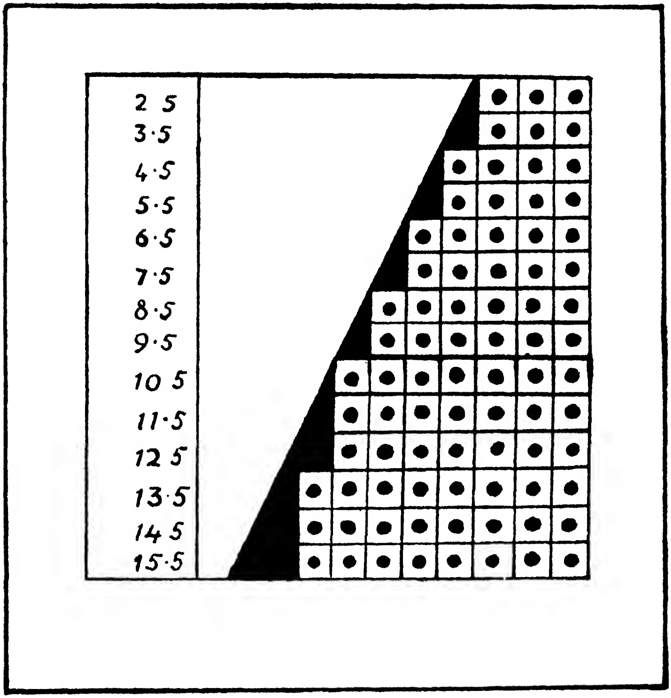

FIG. 18.—How the Limits of the Milky Way may be estimated by means of a mere Series of Numbers.

inclusive there are so many that we have to write their number with 8 figures.

We see that the total number of the stars, descending from magnitude to magnitude, increases with a definite rhythm. Our diagram is not unlike a staircase. Down

to the 10·5 or 11·5 magnitude the steps follow one another at such intervals that if one could lay a plank across them it would just touch the edges of the steps. But after this the rhythm no longer holds good. We see that a figure is lacking in the line corresponding to the 12·5 magnitude; another is lacking in the line corresponding to the 14·5 magnitude; and also in that corresponding to the 15·5 magnitude. If we were to extend our diagram to include the statistics of still fainter stars, we should find that the divergence from the straight line becomes more and more marked as we descend the scale.

Now what does this divergence mean? It tells us that the stars of the Milky Way are not distributed equally "to all infinity", but that their density of distribution gradually diminishes with distance, until at last we come to the *end* of the Milky Way. Thus, it is possible not only to say that the stars of the Milky Way must somewhere "come to an end", but also to calculate *where* the limits of the Milky Way are situated.

According to Seeliger, the stars of the Milky Way, considered as a whole, form a flat *ellipsoid of rotation*, very much the shape of a thick watch with a strongly curved back and watch-glass. The dimensions of the system can only be expressed in tens of thousands of light-years. The longest diameter measures about thirty thousand light-years, and the shortest about ten thousand. In the neighbourhood of the galactic plane, the stars are not only apparently, but actually much closer together than outside this plane.

So much for the outer limits and the general structure of the Milky Way. The details of the arrangement of the stars of the Milky Way have not yet been established. Easton and Arrhenius assume that if our Milky Way could be observed from an infinite distance, it would look like a great catherine-wheel, a spiral; and according to them the two bright streaks in the neighbourhood of the Swan are none other than two spokes of the great spiral.

By his calculation of the dimensions of the Milky Way Seeliger, the late President of the great International Astronomical Society, earned undying fame, and his achievement is not diminished by the fact that it has since appeared that the universe of stars does not actually come to an end at the frontiers which he determined, but that this universe, this system, which must really be called a "local system", is joined on to other hosts of stars, forming with these a sort of "greater Milky Way", whose diameter far exceeds that of Seeliger's galaxy. The actual instrument of this enlargement of our structural universe was, curiously enough, furnished by the stars themselves, and especially by the so-called Cepheids.

. . . . .

The star Delta of Cepheus has the peculiarity of changing in brilliancy every five days or so, in accordance with a very singular rhythm. It is at first comparatively faint; then its brilliance rapidly increases, while after the "maximum" it returns, more slowly, to its original degree of brightness. This rhythm has

other quite peculiar characteristics, which recur, with great preciseness, with every period. Rhythms of exactly the same character are revealed by an extraordinarily large number of other stars. They are known as Cepheus-stars or "Cepheids". Their light "pulsates", as though the starry body were breathing, and to this day we have no perfectly satisfactory explanation of this remarkable phenomenon. One Cepheid pulsates more slowly, taking many days to go through its whole rhythm from minimum to minimum, while in the case of other such stars the period is one of hours only.—Many of these Cepheids are near enough to make it possible to measure their distance by the trigonometrical method. But if we know the distance of a star, and also how much light it transmits to the photographic plate, and if we know its apparent luminosity, it is easy to get some idea as to how many "candle-power" it really emits.—For if I see a light on a hillside which I know to be five miles distant, I can, just because I know the distance, estimate, from its apparent brightness, how bright the light really is: whether it is an electric lamp, a camp-fire, or perhaps a heath or forest fire. (It is not usual for astronomers to speak of "candle-power", as though they were dealing with oil-lamps, or gas, or electric light, but I have already employed this standard of measurement in the chapter on the Sun.) And here a curious relation becomes apparent: the brighter the *actual* light of a Cepheid—that is, the greater its candle-power—the longer is its period of variability. This simple relation proved to be so reliable that it was possible to arrive at

the candle-power merely by measuring the period of variability.

And what followed from this?—There could be no doubt that all those stars which showed precisely the same rhythm of variability as Delta Cephei—and it was found that there were many such stars in all parts of the heavens—must be subject to one and the same law. And it was therefore possible, in the case of even the faintest and remotest points of light in the heavens, provided they exhibited the same kind of variability as the star in Cepheus, to estimate, merely by observing the period of variability, their actual luminosity of so many quadrillions or quintillions of candle-power. Now if I see a lamp whose candle-power I know shining somewhere in darkness, it is a simple matter to calculate its distance. But in one sense every star in the heavens is merely a distant lamp. Given the calculated candle-power of such a starry lamp, if I ascertain its apparent brilliance—that is, its "magnitude"—I can obviously calculate its distance. The procedure of solving a "Cepheid" problem may be summarized as follows:

1. Having chanced to observe the rhythmical variability of a remote star, we recognize it as a Cepheid.

2. We measure its period of variability.

3. From the length of this period, with the aid of a table of calculated values which gives us the precise relation between the period and the *actual* luminosity, or candle-power, we ascertain the latter.

4. Knowing the *apparent* brilliance, which can be

measured, for example, by the blackening of a photographic plate by the image of the star, and the actual "candle-power", we can ascertain the *distance* of the star.

We owe the discovery of the connection between the period of a Cepheid and its real luminosity to an American astronomer, Miss Leavitt. The application of this phenomenon to the enlargement of our conception of the universe was due to Shapley, the director of the Harvard observatory. How Shapley set to work you will read in the second part of the next chapter. For the present, however, we will linger a little longer in our "local" Milky Way; for within its limits there are many wonderful things to be seen besides the Cepheids.

. . . . .

A great many stars are really *double or multiple systems.* It seems to be the rule, in the genesis of a star, that as it spins upon its axis it divides by centrifugal force. It is thus that physically related systems come into existence. A physically related system is one whose individual components have a common movement in space. But it is not always possible to prove that the conjunction of two stars is not merely "optical". One may be much farther away than the other, but it may so happen that we see them almost in line with one another.

You heard something of double stars during our first

survey of the heavens. Mizar and Alkor, at the crook in the tail of the Plough, are a convenient pair for observation with the naked eye. A very much more difficult star to "resolve" with the naked eye is Alpha of the Goat. A still more difficult "double" is Epsilon of the Lyre, near Vega. According to Kolbow, it takes normal sight to divide Mizar-Alkor, good sight to recognize Alpha of the Goat as a "double", and excellent sight to resolve Epsilon of the Lyre.—This latter star, if we look at it through the telescope, has a surprise in store for us. The two components, which even to the keenest eye appear as single stars, are themselves seen to be double. Epsilon is a quadruple star. We call such systems, which are resolved only by the telescope, *telescopic* binary or multiple systems; accordingly as they consist of two components, or of several suns.

A special group of binary stars consists of those stars which even the most powerful telescope cannot separate into their individual components. The existence of such components is detected only by the spectroscope. Two suns are circling round one another in such a way that when one is moving towards us the other is moving away from us. In accordance with Doppler's principle, the dark lines of the spectrum will be displaced towards the blue end in the case of the first star, and towards the red end of the system in the case of the second. This displacement occurs, of course, in the same tempo as the revolution of the two suns, so that we are able not merely to demonstrate the twofold character of

such a "spectroscopic" binary, but also to determine the orbital period of its components.

. . . . .

Castor.—A favourite object for demonstration with a good telescope is Castor in Gemini. The naked eye shows us simply a bright star of the second magnitude. In the telescope we see it as a double star. The two components of the system are of unequal brilliance. It has been calculated that they revolve round one another in a period of some centuries, and it has been found that each of the two components of Castor is itself a spectroscopic binary.

Spica in Virgo.—This star is more than 300 light-years distant from us, and it is only because of its extraordinary real brilliance—which must amount to some quintillions of candle-power, so that it must be a thousand times greater than that of our own Sun—that we are able to see it as a comparatively bright star, a fixed star of the first magnitude. It is a typical "spectroscopic double", consisting of two incandescent balls of gas, of equal brilliance, which revolve about one another in a period of just four days.

Zeta in Cancer (Fig. 19).—This, at first sight, is a very ordinary little star. But the telescope shows us at once that it is double, and on closer inspection we find that it is actually a triple star. Two stars—we will call them A and B—are divided from one another by only one second of arc; they are both yellow in colour, and they circle round one another in a period of two human generations. (A second of arc seems a very small space.

The diameter of the Moon, for example, covers about thirty minutes of arc, or half a degree. A second of arc is only one-sixtieth part of a thirtieth part of this diameter.) Round this pair of stars revolves a third star, C, which is orange in colour, and of about the sixth magnitude. The third star is divided from the

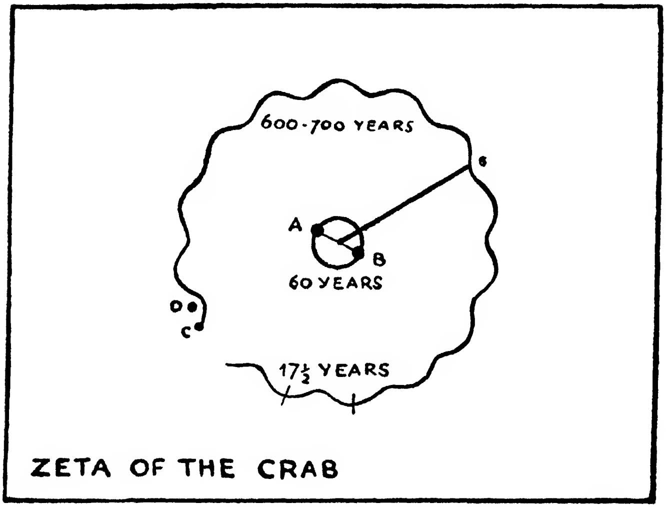

FIG. 19.—A Fourfold System : Zeta of the Crab.

centre of the whole system by about six seconds of arc, and it revolves round the pair of stars, or rather, round their centre of gravity, in a period of six or seven hundred years. But this is not all. We learn from the behaviour of C that this star has a dark companion, round which it revolves in a period of seventeen to eighteen years. The inconspicuous Zeta is a very interesting example of a complex multiple system.

There are many stars of this kind, with dark invisible companions. It often happens, in the case of such a system, that the dark star passes between us and the bright one, producing a partial eclipse of the distant sun. We are notified of this eclipse by the diminished brilliance of the system, and a star of this kind is accordingly placed in the great category of the so-called "variable stars". In principle, all stars are variable, for an absolutely constant luminosity is inconceivable; consequently the category of variable stars is susceptible of very extensive subdivision. Generally speaking, we make use of one of the methods of subdivision proposed by Guthnick, who has found it possible, by means of light-sensitive cells, to measure variations amounting to no more than one-hundredth of a magnitude.

There are "optical variables", like Algol, in Perseus, "dynamic variables", like Beta in Lyra, and "physical variables", like Mira in Cetus; and fourthly, there are the so-called "Novae" or "new stars".

Algol.—This curious star in Perseus has always impressed the observer as mysterious; to the Greeks it was the eye of Medusa, whose glance turned to stone the Sea-Monster (Cetus) to which Andromeda was to be sacrificed. As a rule Algol is hardly distinguishable from Algenib, the brightest star in Perseus. At certain times, however, at intervals of two and a half days—to be exact, of sixty-nine hours—its light diminishes by almost a whole magnitude. From a star of about the second magnitude it becomes, in the course of about four and a half hours, a star of

the third magnitude, and then, at the same rate, recovers its original brightness. This periodical variation is explained if we assume the existence of a dark companion which revolves round the bright Algol and eclipses it when it passes in front of it.—It is possible to make an actual model of this peculiar system. The five million kilometres which in reality separate the two components of the double-star must be reduced to our planetary scale, on which one metre in the model represents a million kilometres in reality.

The bright star, whose mass is about half as great as that of our Sun, becomes, on this scale, a sphere $1\frac{3}{4}$ metres in diameter. At a distance of 5 metres—from centre to centre—is a second body, $1\frac{1}{3}$ metres in diameter. The "dark" companion of Algol may not be actually dark. It is a sun, like Algol, but its luminosity is at all events too small, compared with that of the bright star, to make it possible for us to observe it.—Algol is an "optical variable", or, as it is also called, an "eclipsing variable".

Beta of the Lyre.—This star, which is known also as Scheliak, is of only the fourth magnitude. Its variability, like that of Algol, is due to the revolution of two stars round a common centre of gravity, but with this difference, that a purely dynamic factor, namely, the tidal influence of one sun upon the other, plays an important part in the changes observed. The two bright components, as a result of their mutual attraction, have a somewhat elliptical form, so that we may compare them with two hen's eggs, whose larger ends

are turned toward one another. On the planetary scale the larger star of the Beta system measures a good 32 metres in diameter, and the smaller 24 metres—measuring each along the major axis; so that they are positive giants compared with our Sun, which is no bigger than a coach-wheel. From centre to centre is only 30 metres, so that the surfaces of the two model suns approach to within 2 metres of one another. In a period of about two weeks these colossal bodies revolve round one another, now turning their broadsides to us, and now their small ends, so that sometimes the larger body passes in front of the smaller one, and sometimes the smaller before the larger. The light-curve of this star shows two crests of equal height, and two unequal depressions.

Mira, in Cetus.—Mira, "the wonderful", was discovered not by one of the observatories, but, like many another heavenly body, by an amateur astronomer, the Frisian pastor Fabricius, in the year 1596, in a region of Cetus which was familiar enough to this assiduous observer, but in which he had never before seen anything worthy of remark. Mira is at some times extraordinarily brilliant; then its brightness diminishes until it has sunk far below the level of visibility to the naked eye; it remains invisible for quite a considerable period, and apart from this there are four months—from March to June—during which it cannot be observed, owing to its nearness to the Sun. Its rhythm of variation has been determined; it has a period of eleven months; but its light-curve—the diagram showing the variations of brightness during this period—

is so irregular that Mira remains an enigma to this day. It has been assumed that phenomena of the nature of sunspots on the surface of the star may be responsible for its behaviour; slowly rotating on its axis, it turns now one side to the observer, and now another, and these different sides may be unequally affected by the spots; whose area, again, will have altered during the course of a revolution.

. . . . .

For its discoverer, Mira was a new star. In reality it had existed for eternities, though invisible to all observers.—But even those heavenly bodies which are described as "new stars" have not arisen out of nothing. They existed even before their discovery, but they were so faint that they could not be detected; and it was only some sort of catastrophe that made them suddenly visible: suddenly not only in the astronomical sense, for within a few days or hours they have blazed up with such brilliance that some of them have been visible even in broad daylight. The appearance of such a "new star", as you will readily understand, has always been a great event in the history of stellar research.

. . . . .

In the year 125 B.C. the astronomer Hipparchus beheld a bright star where no star was before. This phenomenon caused him to make a map of the stars, so that in future the newness of any apparent new-comer could at once be put to the test. And as a result of comparing this map with an earlier chart Hipparchus discovered

another phenomenon, which we call *precession,* and which was mentioned incidentally in the first chapter. Precession is the gradual change of position to which all the stars are subject; so that in 2,000 years' time the constellation standing in the western sky on July evenings will be not the Lion but the Crab, and in another 2,000 years the Crab will be replaced by the Twins; so that after the lapse of 26,000 years—or of one so-called "Platonic year"—the constellations will have returned to their present position.

A famous "nova" was the "new star" of the year 1572. It could be seen in broad daylight, and Tycho Brahe, the founder of the Uranienborg observatory on the island of Hven, near Copenhagen, gave an exact description of this phenomenon.—The observations of new stars are almost as old as history itself. Of recent years the "novae" of 1901 and 1918 have attracted much attention. The last remarkable "nova" appeared in 1925.

. . . . .

Where satisfactory explanations are lacking there are dozens of hypotheses. It has been suggested that a star covered with dark spots, of the same nature as our sunspots, may, after the fashion of Mira, suddenly turn an unspotted area towards us. But the sudden nature of the phenomenon, and the enormous difference of brightness, are not adequately explained by such an assumption.—A direct collision between two dark stars would perhaps suffice to create such a blaze of light that an invisible system would become a star of the first magnitude, or even brighter. But it can be shown

that such collisions must be extremely rare, whereas the appearance of "novae" is of such comparatively frequent occurrence that we are once more confronted by a great discrepancy. From the records alone we learn of dozens of "novae", while the probability of a collision between two stars is so small that only *one* direct collision can occur in a period of many milliards of years.—Even the assumption of a violent tidal action between two stars fails to explain the phenomenon.

. . . . .

It is assumed, as a rule, that a dark star is travelling through space. Now, space is demonstrably interspersed with dark cosmic nebulae. There are dark nebulae which cover many square degrees of the heavens; there are others which extend as dark masses into brighter nebulae. The probability that a great mass of this kind may lie in the path of a star is incomparably greater than the probability of a collision between two stars. Just as a meteorite rushes into the atmosphere of the Earth, ignites, and is extinguished, so such a dark star may ignite in a cosmic cloud. The result is a mere transient blaze; after a few days the distant world-conflagration is so far extinguished that the new star is no longer conspicuous in the ranks of the old stars, and in a few weeks' time it survives only as a faint telescopic point of light.

. . . . .

Nowadays every star is regarded as a specimen, much as we should regard a compound to be analysed in

the laboratory, and we endeavour to explain even the appearance of a new star by the nature of its substance, by the structure of the atom.

An original explanation was suggested on the appearance of the last bright "nova", which was accidentally discovered by a South African postal official, and entered in the charts of "new stars" as Nova Pictoris 1925.

From the behaviour of the Fraunhofer lines in the spectrum of the star, and the changes in the spectrum at the critical moments of maximum and minimum brightness, Hartmann concluded that we must assume that the star positively "inflates itself" until the maximum brightness is reached, and then actually "bursts", and finally collapses, with convulsive tremors. From the Dopplerian displacement of the Fraunhofer lines Hartmann deduced a velocity of expansion of 140 kilometres per second. If this assumption is correct, then at the moment of maximum brightness the star must have a diameter of 600 million kilometres.—On our planetary scale this would be a sphere of some 2 kilometres in circumference, so that it would take a good twenty minutes to walk round it. Compared with this our Sun, as big as a coach-wheel, and our Earth, the size of a hazel-nut, seem almost imperceptible.

CHAPTER VIII

THE EVOLUTION OF THE STARS AND THE STRUCTURE OF THE UNIVERSE

NATURAL science knows nothing of the conception of "eternity" in respect of the milliards and milliards of individual things and beings to which it turns its attention. Even the stars are not eternal. They are not only subject to change; sooner or later they cease to exist as stars. They are just as subject to a definite evolution as any living, organic being. Every star has its own duration of life.

Only a few years ago our attempts to elucidate the evolution of the stars were based more or less on the analogies of the phenomena of primitive experiment.

The star Vega in the Lyre is white, with a tinge of blue; the Pole-star is bright yellow; Aldebaran in the Bull is orange-coloured; Antares is red as blood. The same range of colours is displayed by a bar of white-hot iron in a dark room. At first it is a glowing white; then it assumes a yellowish tinge; then it turns reddish-yellow, then bright red, and finally a dull red, until at last it is no longer visible. It is just the same—so the astronomers used to say—with the stars. A star is formed out of a nebula, and it shines with the bluish white radiance of an arc lamp. The white stars are therefore the youngest; in time they turn yellow; our Sun, for example, is no longer quite youthful; it is a yellow star. Stars of still greater age are orange-yellow, and the red stars are nearly dead. They turn

dark red, and then brown, and gradually they cease to shine.

So it was generally thought; and it was only some fifteen years ago that this opinion was modified, giving way to a new conception of the genesis of the stars. One of the principal reasons why the old ideas had to be abandoned was the discovery that some of the better-known bright red stars were of such enormous size, and of such low density, that one was forced to regard them as nebular structures, and as representing the beginning rather than the end of the evolution of a star, if one did not wish to relinquish the well-founded nebular hypothesis according to which stars are formed out of nebulae.

. . . . .

Betelgeuse in Orion is a conspicuously red star. That its diameter must be enormous compared with that of the Sun, and so large as to upset all previous notions of the size of the stars, was assumed even before Michelson's famous measurements; but he was the first to succeed in determining, with great exactitude, its diameter in kilometres. His method is too special to describe in detail. It is not a direct method: that is, it does not involve the measurement of a length, or even of an arc in seconds or fractions of a second; the diameter of a star at a distance of 170 light-years is too small to be directly measured. A forty-seven thousandth part of a second of arc is beyond the scope of the finest of ordinary measuring-instruments. The jagged appearance of a star is due to an optical illusion;

the punctiform image of the star is expanded over an area which extends far beyond the circumference of the star itself.

The rays of light proceeding from the star were made to play upon one another, to "interfere", and a method of measurement which depended on the *interference* of light, as the physicists call the phenomenon, gave the diameter of Betelgeuse as no less than 380 million kilometres, or 235 million miles.

Let us have recourse to our planetary scale: 1 : 100,000,000. The Sun is a sphere whose circumference is equal to the circle which I can describe in space with my outstretched hand. Our Earth is once more a hazel-nut, and revolves at a distance of 150 metres round the Sun. And here is the astonishing thing: the radius of Betelgeuse is larger than the distance from the Sun to the Earth! This gives us a sphere which would contain the whole of the Earth's orbit, with room to spare. The volume of the Sun is about a million times that of the Earth; but the volume of Betelgeuse is much more than a million times greater than that of the Sun. Betelgeuse is a "giant star".

. . . . .

Now, it is possible also to ascertain the weight of a star. For example, in the case of those stars which are attended by companion stars, we are able to deduce, from the nature of the orbit, the force with which the one star acts upon the other, and consequently its mass. Researches of this nature, and of other kinds,

have shown that there are stars which are heavier than our Sun, and stars which are lighter; but the weight of the star varies only within comparatively narrow limits. There are stars which are about seventy times heavier than the Sun, and stars which are about ten times lighter; but there is no star which is a thousand times heavier. What follows from this, when we have learned that Betelgeuse exceeds the Sun in volume more than a *million* times? Well, Betelgeuse must consist of extraordinarily light material; it is as thin as air, and even thinner; it is a nebulous star, an incandescent mist, which has only just been formed out of the primitive materials; it is one of the most recent stars. The old notion, according to which a bright red star must be an old star, has to give way before a new conception. But the new theory also is based in the first place on the colours of the stars; a conception which requires more precise definition.

. . . . .

What is the colour of a star? Simply the total impression of the hundreds of shades which go to make up the light that reaches us from the star. And these very fine gradations of colour can be analysed only by the spectroscope. The spectroscope shows us that about 99 per cent. of all the stars—that is, almost all the stars, so far as one can observe them with the aid of optical instruments—may be divided, in respect of their spectra, into six groups. This does not mean that the representatives of these groups are composed of different chemical elements. The differences in their

spectra are much more dependent on the different surface temperatures of the various stars; for, according to the temperature, now one element will be especially luminous, and now another. If in the spectrum of our Sun the lines denoting the presence of metals are especially prominent, while in the spectrum of Sirius the hydrogen lines are most conspicuous, this only means that in the temperature of the Sun—about 6,000°—the metals are incandescent, while in the much higher temperature of Sirius—which we have reason to believe is about 11,000°—hydrogen emits the most light.

Miss Cannon was the first to divide the stellar spectra into groups, and to denote these groups by the letters of almost the whole of the alphabet. But it was found that groups A, B, F, G, K and M were for all purposes adequate, since all the other groups had so few representatives that the whole of them taken together constituted only 1 per cent. of all the stars. If we reverse A and B, the series B, A, F, G, K, M represents not merely the types of spectrum, but also a series of diminishing stellar temperatures, for the B-stars are the hottest; next come the A-stars, then the F-stars, and so on. And each of these types of star has its own distinguishing qualities.

1. The B-stars are the hottest of this series. We may also call them stars of the Orion type, since they have some prominent representatives in that constellation. They are white in colour; their surface temperature is from 16,000° to 20,000°. The hydrogen and helium lines predominate in the spectrum. A quite small

group, the O-stars, have temperatures exceeding even that of the B-stars.

2. The A-stars, known also as Sirius-stars, after their chief representative, reveal average temperatures of 11,000°, and, like the B-stars, are white. The helium lines are no longer prominent; the spectra of the metals are faintly visible; on the other hand, the hydrogen lines are exceptionally brilliant.

3. The F-stars. In their spectrum the metals are more plainly visible. Their colour is pale yellow; their temperature about 8,000°. A typical representative is the Pole-star.

4. The G-stars, which are yellow, are often called the Sun-stars, because our Sun is among their representatives. The metallic lines are predominant; the surface temperature, as in the case of the Sun, may be estimated at 6,000°.

5. The K-stars are already tinged with red; they are orange-coloured, like their representative Arcturus. Their temperature is only 3,500° to 4,000°; it is so low that in the superficial strata chemical compounds are able to form which cannot exist at higher temperatures. Their spectra show broad dark bands.

6. The M-stars, like Betelgeuse and Antares, have still more strongly marked dark bands in their spectra; they are red, and theirs is the lowest stellar temperature: about 2,700°.

. . . . .

All the data relating to these types of stars have been obtained by purely physical methods, and in particular

by spectroscopic analysis; and the succession of types described forms a natural series only in so far as the temperatures of these types diminish progressively from B to M. There were three possible theories, based on this series of spectra, of the genesis and history of a star. One theory was in accordance with the old obsolete idea that a star must run through these colours just as a bar of white-hot iron does as it cools. Yet the reverse process was equally conceivable: the colours might be comparable to those of a bar of iron gradually heated from red to white. But neither of these explanations has proved to be acceptable, and we have now arrived at a third theory; one which is in accordance with an idea that was expressed some decades ago by Lockyer, and which is illustrated by Fig. 20.

. . . . .

Somewhere in the universe atoms or molecules gather together and form a nebula. The constituents of this nebula are drawn together as a result of the general gravitation which is always acting between the particles of any mass. By the great resulting pressure the mass is heated until it reaches a temperature of 3,000° or so; and the nebula forms itself into a sphere of the size, perhaps, of Antares or Betelgeuse. It is now a red "giant star". Its spectrum, to begin with, is of type M. This red giant continues to contract, as the result of the gravitation of its mass, so that the temperature continues to rise. It reaches 4,000°, and the spectrum of the star resembles that of Arcturus in Boötes. Then the temperature rises to 6000°; the star is still a giant

—like Capella—but the red colour has now changed to yellow. Later the spectrum may be like that of the Pole-star, type F; the temperature is now from 7,000°

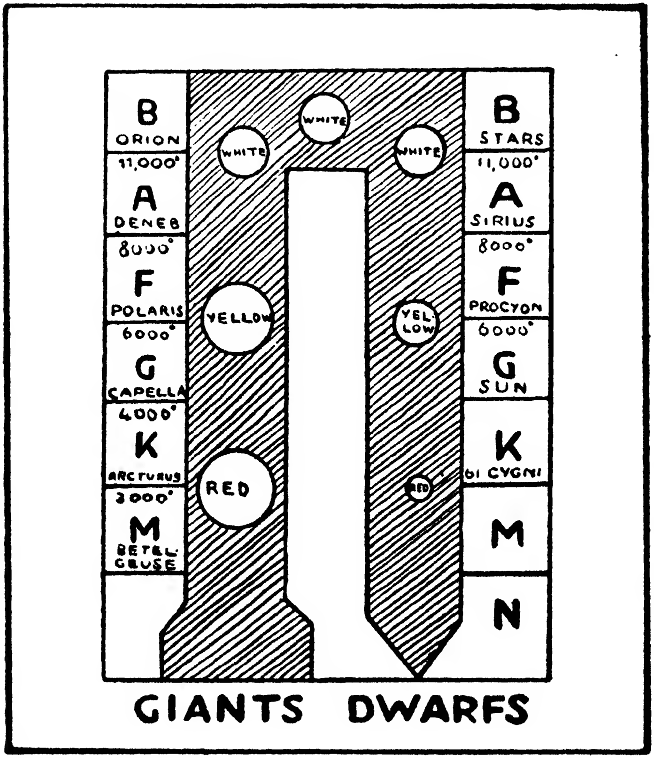

FIG. 20.—Stellar Evolution and Devolution: Giants and Dwarfs.

to 8,000°. Then it becomes a star of type A, like Deneb, with a temperature of some 11,000°; and at last the hottest stage is attained. It is now a star with the

temperature of the white "Orion-stars": somewhere about 20,000°.—Betelgeuse in Orion is an exception in that constellation.—The white-hot Orion stars, and the small group of so-called O-stars, are at the summit of stellar evolution. An O-star or B-star is still very voluminous; it is still a "giant star", but it is beginning to decline. The colour passes through the same changes as before, but in reverse order; the same spectra are shown as before, but these again are in reverse order. The constant radiation into space cannot be made good even by further compression. The result is that the temperature of the star falls, and continues to fall. The compression increases rapidly, and the giant star becomes a small one, and finally a dwarf. Sirius, for example, in spite of its high temperature, is a representative of descending evolution; our Sun is a yellow dwarf, and 61 Cygni, which was the first star whose distance we were able to measure, is one of the very ancient dwarfs. It is not vouchsafed to every star to reach the summit of its career as a B-star or an O-star. According to the mass which it "inherits", so far will it go and no farther. Our Sun, for example, if Eddington is correct, must have begun to decline somewhere between the F-stage and the A-stage; so that it has never been so hot as Sirius, and is now growing old. Stars which have only half the mass of our Sun cannot, according to this theory, evolve higher than the G-type. Only stars whose mass is double that of our Sun can reach the B-stage, and only stars whose mass is four times as great can ever become O-stars.

. . . . .

Quite recently the views of the astrophysicists concerning the evolution of the stars have undergone certain interesting modifications, most of which relate to the processes in the interior of the stars. In 1927 the eminent American astrophysicist Abbot summarized as follows the career of a star:

"Out of the formless nebula, whose atoms were brought into being by some means of creation which we do not possess or understand, red giant stars, far less dense than air, were formed. Under the combined influences of gravitation and radiation, these giant stars grew hotter and denser. With rising surface temperatures, their colors advanced through yellow to white and blue, attended by the familiar changes of spectra, and by a great decrease in diameter, but without much change of total brightness. Arrived at temperatures so superlative and densities so considerable, the flow of radiation from within to heat the surface is hindered by absorption owing to shortness of average wave length, so that the surfaces no longer maintain their maximum temperature or radiation. Yet the inner temperatures continue rising because the stars, though so dense, retain the characters of perfect gases. For their atoms are reduced by separation of nuclei and electrons. The process of cooling at the surface continues until the star, born a red giant, dies a red dwarf, having not only attained great density by contraction but lost much mass by annihilation.

This "separation of electrons and nuclei" calls for

further explanation. Astrophysics and atomic physics—the science of the star and that of the atom, the science of the macrocosm and that of the microcosm—work in close co-operation and mutual reference. "Our final aim is to weld cosmic and terrestrial physics into one all-embracing science."

That branch of science which concerns itself chiefly with the structure of the stars is still evolving; and almost daily some new solution of its problems, or at least some new idea, which may be fruitful of results, or, on the other hand, may be only ephemeral, has to be taken into consideration. To-day, therefore, it is more than ever difficult to give, in a few paragraphs, a general survey of the latest theories of the genesis and structure of the stars. I shall accordingly confine myself to a single example: to the problem of the companion-star of Sirius; which is actually not one problem but several, so that I shall have to allude to several of the newer theories of stellar evolution.

. . . . .

Sirius is about nine light-years distant. It is the brightest of all the fixed stars, and has naturally always been a favourite object of observation. Now there was something about Sirius that puzzled the astronomers. The determination of its position in the heavens, in relation to other and smaller stars, showed that it moved in a singular fashion, which could only be explained by assuming that Sirius was really a double star, whose companion, however, was so small that it could not

be distinguished in the dazzling blaze of the Dog-star. The existence of a companion-star was first assumed by Bessel in 1844, and eighteen years later Clark, in America, succeeded in actually observing it.

It is a white star. Its distance—which, of course, is that of Sirius—was already known; consequently, by measuring the surface radiation—that is, the brightness of the star—it was possible to ascertain its diameter. This was no matter of speculation; nor is there anything hypothetical in the calculation of the masses of the two components of a binary system. And the mass of the companion-star was duly determined.

So both the mass and the volume of the star were precisely known: *empirically* known, so to speak: the results being based on experience and observation. Nothing was simpler than to calculate the specific gravity or density of the star: the density equals the mass divided by the volume. But the result was a mysteriously high value: the density of the companion-star proved to be 53,000 times that of water! Platinum had always been regarded as the heaviest of all substances; and the specific gravity of platinum is 21·5. And now it appeared that the density of this singular star was 53,000!

. . . . .

If there is one science which teaches us mortals to recognize and abandon our prejudices, and compels us, if we serve it with humility, to accustom ourselves to entirely new conceptions, that science is modern

astronomy. There are more things in the heavens than are dreamed of on Earth.

Now, we should like to accept this value of 53,000. But how are we to find it credible?—We will leave it for the moment, and turn to consider the structure of matter. The scientists have chosen to refer the masses and densities of different substances to those of water, a chemical compound of comparatively simple structure. The smallest thing to which we can give the name of "water" is the molecule of water: a thousand times smaller than the tiniest object which we can see through the most powerful microscope. The molecule of water consists of atoms of two elements—oxygen and hydrogen.

The word *atom* means a thing *indivisible*. We know to-day, however, that even an atom is "a universe in itself". It consists, firstly, of a central nucleus, the *proton*, and this proton is envisaged as a particle carrying a minute charge of positive electricity. Round this nucleus circle the negative *electrons*, "as the planets circle round the Sun". In the hydrogen atom there is only a single electron; in iron there are twenty-six; and in radium eighty-eight electrons revolve in their orbits round the central nucleus. They revolve with such speed that they make more revolutions in a second than the wheels of a racing motor-car would make in millions of years.

. . . . .

Let us be so bold as to "look at" such an atom of hydrogen (Fig. 21).—In order to realize the relative

sizes of the stars and the planets we had to employ a reduced scale. Here we must enlarge our atom a thousand billion times. The nucleus of the hydrogen atom, even on this grotesque scale, will be only 2 millimetres in diameter. The electron will have a diameter of 3·8 metres; that is, it would nearly fill a moderate-sized room. And the distance of the electron from the

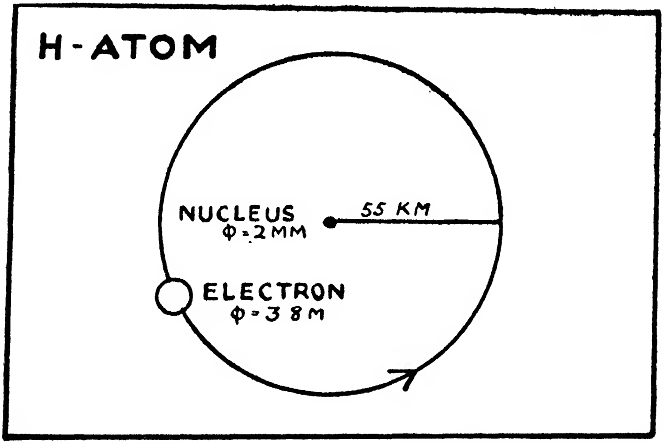

Fig. 21.—An Atom of Hydrogen magnified one Thousand Billion Diameters.

nucleus would be no less than 55 kilometres, so that we must have recourse to a map in order to appreciate the structure of the tiny atom.

As we have seen, the structure of the atom has been compared to a planetary system. It is true that the Sun of the atom, the nucleus, is much smaller than the planets of the atom, the electrons. But there is another way of regarding their respective magnitudes.

If, disregarding their cubic content, we consider their electrical charge, we shall find that in general the central body of the atom has a larger charge than that carried by the individual electron. In the atom of radium, for example, the nucleus possesses as great a charge of electricity as all the eighty-eight electrons together.

But the comparison of the atom with a planetary system is one that will bear scrutiny. An atom is not a system in which one component is welded to the rest. The atomic system is as "open" as the solar system.

Here is one component, there another, and there another, and between them are comparatively large empty intervals. Ordinary matter—every kind of substance—is composed of atoms in which there are comparatively great empty spaces. Matter is not so closely packed that it could not, by some means or other, be still farther compressed. But does such a thing ever happen?—Not on our Earth. Not even in our best-equipped laboratories have we any means of increasing the compactness, the density, of the atom.

But a star is a very wonderful apparatus. It is a crucible in which matter is subjected to temperatures which are far beyond the resources of our laboratories.

Eddington, some years ago, estimated that the pressure, at the centre of a "normal star"—that is, a star of average mass—must be equal to the pressure of 20 million atmospheres, and showed that 5 million degrees Centigrade was probably not too high an estimate for the temperature at the centre of a normal star. To-day still higher temperatures have been

estimated. It is believed that even our Sun, which possesses a lower surface temperature than other stars, reaches a temperature of 70 million degrees in the interior. There is a star in the constellation of Argo, in the Southern heavens, which possibly attains a temperature of 300 million degrees, while another is estimated to reach a temperature of 500 million degrees at its centre. In such heat, of course, all matter is literally "disjointed". The atoms are totally destroyed, and their nuclei and electrons lie side by side in intimate union. Matter, in short, is more closely packed. If in our enlarged "atomic model" we bring the electron, which is 55 kilometres distant from the nucleus, right up to the latter, we shall reduce the diameter of the "atomic area" from over 100 kilometres to a few metres. This would explain a more than 53,000-fold increase of the mean density.

. . . . .

And now to turn from the structure of the atom to the structure of the universe!

No one to-day is greatly interested in the fact that the Earth is round. Everyone knows that he can take a ticket round the world if he happens to have enough money. But what of the old days? Was it not then an unheard-of thing to believe that the flat disc of the Earth had suddenly become curved?

No one to-day is greatly interested by the fact that we can bridge the oceans by means of "wireless". Even to our children wireless telephony is no longer a miracle; only we who recollect its first beginnings,

who remember how delighted we were with the first scratchy sounds that were actually said to have come to us through the ether—only we, who have followed the whole development of "wireless" and broadcasting, are in a position to realize the real value of the invention.

In just the same way, one must have followed the problem through all its stages in order to understand what it meant to the scientific world to realize that the Milky Way is not merely so stupendously vast that it would take a ray of light 30,000 years to travel from end to end of it, but that it is now to be regarded only as a "local system", a part of another galactic system, a sort of "greater Milky Way", whose length and breadth are something like ten times those of our own universe.

In the year 1921 two distinguished American astronomers, Shapley, the "revolutionary", and Curtis, the representative of the "conservatives", published a memoir in collaboration, in which they submitted the *pro* and *contra* of a certain question to the scientific world. This question was none other than the problem of the shape and dimensions of the universe. Was the universe of the Milky Way of the size which had hitherto been accepted, or was its diameter ten times and its volume a thousand times as great? This was a problem which could not be regarded with indifference.

. . . . .

But how was it that the question came to be asked at

all? Had Seeliger, the great expert in stellar statistics, been working on mistaken lines? Was his theory correct, but was there perhaps an error in his calculations?—No: errors of calculation are unthinkable in problems of this kind.

The new ideas as to the dimensions of the universe were inspired by those wonderful celestial objects, the "globular star-clusters" (Fig. 22). These have already been mentioned in an earlier chapter: in Hercules there is a cluster of this kind which can be seen with

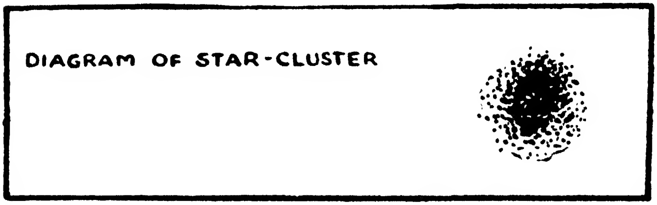

FIG. 22.—A globular Star-Cluster.

the naked eye. The telescope shows us that its outline is definitely circular. The centre is bright, an indistinguishable mass of light. But by observing the edges of the cluster we clearly perceive that the whole structure consists of separate stars; it is like a spherical swarm of midges, and every midge is a sun like our own, and perhaps even larger and brighter.

It was found to be possible to number the stars in such a cluster. It was photographed, and on the photographic plate equidistant concentric circles were described round the dense central point, so that a figure like a rifle-target was superimposed on the

mysterious universe. And thus it was possible, by noting the increase in the density of the stars from the outer edge to the centre, and ascertaining the law of the increase from ring to ring, to determine the total number of stars in the whole cluster. On the whole, however, it appeared that these clusters—there are only about ninety of them—do not differ very greatly in their composition. They are, in a statistical sense, like systems, with equal numbers of stars and equal volumes. There was therefore no doubt that those spherical clusters which seem comparatively large to us—as, for example, the cluster in Hercules, or that in the Centaur, which is the finest of all—are relatively near to us, while the faint "telescopic" clusters are relatively remote. This point was not under discussion. If the calculation of probabilities has any meaning at all, the astronomers were on the right track. And there was no doubt as to the relative distances of the clusters. As for their distribution in the organism of the starry universe, this, at first sight, did not seem to present any problem, for all the globular clusters were situated in the neighbourhood of the Milky Way. They must therefore belong to the galactic system.

. . . . .

But even in the globular clusters those remarkable stars, the Cepheids, were represented. In the case of these stars it was possible, given the period of their variation, to ascertain their candle-power, and by comparing this with their apparent brightness, or with the impression produced on a photographic plate, it

was possible to determine their actual distance. But if the distance of the Cepheids was known, so was the distance of the globular clusters which harboured them. Even in the case of the cluster in Hercules, which was known to be one of the nearest, it was found that the Cepheids contained in it were so remote that they could not be reckoned as belonging even to a Milky Way with a diameter of 30,000 light-years. Shapley—still with the aid of the Cepheids—found that other clusters were even more remote, and he finally determined distances of 100,000 light-years in the one direction, and 200,000 light-years in the other.

There was nothing for it, then, but to regard these globular clusters as universes altogether outside our galactic system. They must surround our "local" Milky Way as the moons surround Jupiter, or—and this conception proved to be the right one—we must assume that there lies, beyond Seeliger's Milky Way, an extension of the same, in which these clusters are embedded.

Shapley's theories concerning the globular clusters were victorious. There is actually a "greater Milky Way", a "greater galactic system", whose diameter is about *300,000 light-years*. We must envisage it as built entirely of star-clouds, one of which—and a very large one—is our own Milky Way, whose diameter is only 30,000 light-years.

Other formations of a similar character to our lesser Milky Way are the *Magellanic Clouds*, not far from the South Pole of the heavens. Not only have the astronomers succeeded, by observation of the Cepheids con-

tained in them, in ascertaining their distance, but they have also been able to calculate the movement of these systems. They are about 100,000 light-years distant,

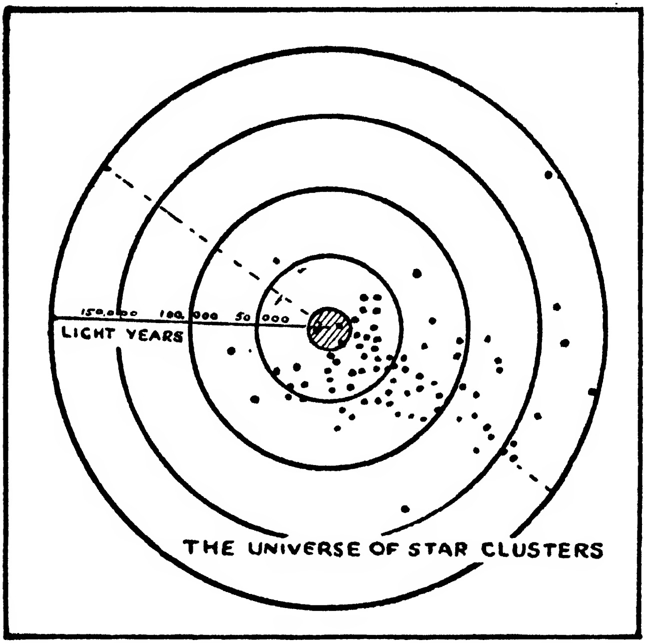

FIG. 23.—The Universe of Globular Star-Clusters: the Greater Galactic System.

and are moving away from us at a speed of about 200 kilometres per second.

. . . . .

The diagram of the "universe of the globular star-clusters" (Fig. 23) shows us our Earth and Sun as

situated, if not "in reality", yet for practical purposes, at the centre of the diagram and of the smallest circle. About us lies the flattened structure of the lesser Milky Way, which is denoted by a shaded circle. Round the central point concentric circles are drawn, at distances representing 50,000, 100,000, 150,000, and finally 200,000 light-years.

Each globular cluster is indicated by a black dot; and we can read off the extent of the system from the concentric circles. We see that in one direction—as a matter of fact, in the direction of Sagittarius—it extends to a distance of 200,000 light-years, but in the opposite direction barely half so far. Our "local" system, and with it our Sun and Earth, are therefore far removed from the centre of the great galactic system.—Each of the globular star-clusters is, on the average, so large that a ray of light would take 100 years to travel through it. The many thousands of stars in such a cluster are nearer to one another than our Sun and its neighbour stars, the average distance between them being about one-third of the distance between the Sun and the nearest stars (Fig. 12).

. . . . .

Besides these globular star-clusters there are clusters of other types: for example, the "open" and the "moving" clusters.

The seven small stars in Taurus known as the Pleiades, and a splendid double cluster of stars in Perseus, and many other clusters, are of the open type. There

are good reasons for regarding these open systems as disintegrated globular clusters.

The group of the Hyades in the head of Taurus, and also the Bear family, to which not only the stars in the Great Bear, but also, among other stars, Sirius and a star in Leo belong, must be regarded as a separate system by reason of their common movement through space. They have been given the name of "moving clusters". They are modest examples of the great wandering hosts of stars which are distributed throughout the heavens, and which, as "star-streams", constitute an interesting chapter of modern astronomy.

The star-clusters, though they belong to a category of their own, are often included in the list of the nebulae. Their inclusion in this list has to-day only a historical significance. The older astronomers, whose telescopes were less efficient than our modern instruments, were often doubtful as to whether a small object was a star-cluster or a nebula.

. . . . .

The *nebulae* are so called because on cursory observation they have the appearance of clouds of light. The telescope shows us that there are several quite distinct classes of nebulae: the "true gaseous nebulae", the interesting "planetary nebulae", and—most important of all—the "spiral nebulae", which may more reasonably be called spiral *universes*. The gaseous and planetary nebulae belong without a doubt to our Milky Way, while the spiral nebulae must be regarded as sister universes.

A true gaseous nebula is the nebula beneath the belt of Orion. There is another gaseous nebula in Taurus. It has the shape of a crab, while another nebula looks like a wind-blown veil. We are not yet quite clear as to the cause of the luminosity of these gaseous masses. Such nebulae often contain bright stars; for example, the seven stars of the Pleiades are embedded in a luminous cloud.

It has been assumed that these gaseous nebulae owe their luminosity to these bright stars: just as the reek of a great city appears, at a certain distance, as a shining cloud; and in this case we know that the cloud is illuminated by the street-lamps. But it is also possible that the central stars cast "invisible rays" on the adjacent nebula, and so excite its luminosity.—This assumption is based on the results of laboratory experiments.

. . . . .

Very remarkable are the *planetary nebulae*, so called because they are often as round as the discs of planets. They have a plastic, transparent look, and almost always contain a central star. Measurements of the radiation from these stars have shown that they are hotter than any of the six types B, A, F, G, K, M. The temperature of some of these stars is estimated at 30,000°.

It is possible that such nebulae consist of the products of radiation emitted by their central suns.

These stars are either O-stars, or are closely related to them. Just as we are not certain of the nature of

these planetary nebulae, so we are unable to assign them their exact place in the structure of the Milky Way.

A well-known planetary nebula is the "Ring nebula" in the Lyre. Seen through the telescope, it looks like one of those smoke-rings which a skilful smoker blows into the air. We must regard this nebula as a transparent sphere, of which we perceive only the outline. This ring-nebula, like other planetary nebulae, possesses a central star, which is visible in photographs,

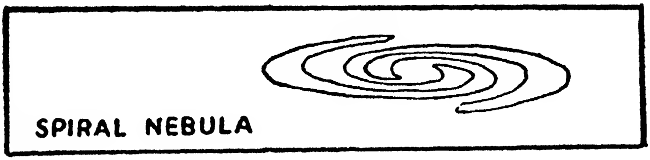

FIG. 24.—Diagrammatic outline of a Spiral Nebula.

although it cannot be seen by the eye. It appears to emit ultra-violet light, which we cannot perceive directly with the eye, but which leaves plainly visible traces on the sensitive plate.

. . . . .

We now come to the *spiral nebulae* (Fig. 24).

In an earlier chapter I told you that our eyes are able to bridge distances so great that the boldest imagination is powerless to conceive them. I had in mind the nebula in Andromeda, concerning which the most eminent astronomers are to-day convinced that it hangs in space at a distance of almost a million

light-years. When we look at this nebula we are seeing light which left it a thousand times a thousand years ago, travelling its 186,000 miles per second, until to-day it strikes upon our eyes. This nebula can be seen with the naked eye.

The telescopic view of this spiral nebula reveals a most curious formation. From the centre spring two arms, which wrap themselves spirally round the nucleus. We have a typical spiral nebula before us; but since we are not looking "down" upon it—since our line of sight is inclined at an angle to its principal plane—we see it with elliptical contours.

In order to find further spiral nebulae, draw a line from Benetnash (Fig. 2), the last or outermost star in the tail of the Plough (B), to Denebola (D) in the Lion. Divide this line by two points, G and H B, into three equal parts. H B stands for the Hair of Berenice, a fascinating object, which is revealed by the telescope as an accumulation of spiral universes like that of the Andromeda nebula. At G there is a very fine and easily separable binary star, in the constellation of the Greyhounds; this constellation contains a magnificent spiral nebula, whose central region has an almost circular circumference.

. . . . .

That the spiral nebulae are universes, which are divided from our own by enormous distances, was long suspected. The astronomers were inclined to regard them as sister universes to our Milky Way, as distant islands in the ether. Even five years ago the more

cautious experts declined to express a definite opinion as to the cosmic position of the spirals. Shapley, however, the astronomer, who enlarged the bounds of our Milky Way, gave it as his opinion, in his controversy with Curtis, that all the spirals are situated within the universe of the globular clusters, and are therefore to be regarded as components of our greater Milky Way.

The stars of which the Andromeda nebula was believed to consist were, for the most part, indistinguishable, especially in the outer regions of the spiral, though spectroscopic observations enabled us to deduce their existence.

Two or three years ago, however, Hubble, at the Mount Wilson Observatory, with the 100-inch reflecting telescope, obtained photographic evidence that this nebula consists entirely of stars: that is, of suns. Here is a whole universe of stars, with all the wonderful features of our own Milky Way.—And so to-day, as far as we can judge, the problem of the spiral universes is solved.

. . . . .

Among the wonderful features of the Andromeda nebula there are "new stars"; there are—most fortunately—those mute but reliable sources of information, the Cepheids, whose variability can of course be determined quite irrespective of their distance. Hubble, relying on the Cepheids, finds that the Andromeda nebula is nearly a million light-years distant.

Even the professional astronomer, who observes the stars day after day, is filled with awe at the thought

of the stupendous distances which reveal themselves even to the naked eye.

The spirals which I have mentioned are only a few examples of the hundreds of thousands which are revealed by the photographic plate, and there is reason to believe that the universe of these spirals, at all events in the direction of the "Hair of Berenice", extends to a distance of a hundred million light-years, or more than six hundred trillion miles. Hubble estimates the range of his telescope to be 130 million light-years.

. . . . .

As long ago as 1781 Lambert, in his "Cosmological Letters", made certain suggestions as to the structure of the universe as a whole:—Our Sun is a star: it forms, with its planets and comets, a system of the first order. Such solar systems are gathered into great clusters; these are systems of the second order. Lastly, our Milky Way is built up of such clusters of stars, and is thus a system of the third order, and doubtless such Milky Ways are combined to form a larger system of the fourth order, etc.; and so on to all infinity. The universe is infinitely great, and the mass of all the stellar systems is infinitely great.—So thought Lambert. Here was a bold "explanation" of the universe. Whether it was not too bold was for the astronomers to decide. And in the course of time two eminent experts examined and criticized Lambert's theory.

To begin with, Olbers, in Bremen, over a hundred years ago, objected that if the whole universe were really

infinitely full of radiant stellar matter, the starry heavens would be as bright as daylight.

More recently (in 1895) Seeliger showed that Lambert's hypothesis of an infinite starry universe was for a second reason untenable. For if the universe consisted of a literally infinite number of stars and stellar systems, the total sum of the forces of gravitation, however small, of this infinite number of stars would be so stupendous that it would be quite impossible for our planets to move quietly in their orbits in accordance with Newton's law. The harmony of the solar system would inevitably be destroyed by the overwhelming influence of a universe whose mass was infinitely great.

Our material universe could not be infinite; it must somewhere have its limits; but how it was bounded, and where, was still a mystery.

. . . . .

In 1922, in one of the publications of the Swedish Academy, the astronomer Charlier asked how an infinite universe like that suggested by Lambert could be built up, and further, what would be the character of its structure. He began with a purely theoretical discussion of the matter, but in the end certain concrete conclusions were arrived at. I will try, in the most elementary fashion, to explain the nature of Charlier's mathematical thesis, or, rather, of the argument based upon his calculations.

I expect you have heard of the story of the peasant

who invented the chess-board, and the Shah of Persia. As a reward for his invention the peasant was to receive one grain of corn for the first square on the board, two for the second square, four for the third, and then 8, 16, 32, and so on; in short, for each successive square he was to receive twice as many grains of corn as were paid for the preceding square.—The result is impressive. The crafty peasant ought to have received a present of 18 trillion grains of corn, so that the crown of Persia is still in his debt, for there is not so much corn in the whole world. If the chess-board had had an incalculable number of squares it is obvious that the sum of all the quantities of this mathematical series would really be infinitely great. And it seems at the first glance that the sum of all the numbers of an infinite series must under all circumstances be infinitely great. Yet this is not the case. There are exceptions. A further mental experiment should make this clear.

My work-table is just 2 metres in length. I measure off 1 metre along one of the long sides, and make a notch where this metre ends—that is, just in the middle of the edge of my table. From this mark I measure a further half-metre, and make another mark. To the length I have now marked off I add a quarter of a metre, then an eighth, then a sixteenth, and so on, the last length measured always being half that of the preceding length. In imagination I can do this a hundred and indeed a million times, always halving the lengths added.

Now, supposing that I repeat these measurements *ad infinitum*, what total length have I measured? Shall

I ever come to the end of my writing-table? Not in a day, nor yet in a thousand years.

What have we learned from this imaginary experiment? Firstly, there are series which possess an infinite number of terms: for example, the series "1, 2, 4, 8, 16, etc. . . . to infinity". This sum is, of course, infinitely great.—Secondly, there are other series, also possessing an infinite number of terms, such as the example which I have just given you: "1 m., $\frac{1}{2}$ m., $\frac{1}{4}$ m., $\frac{1}{8}$ m., $\frac{1}{16}$ m., etc. . . . to infinity", whose total sum is *finite*. For I cannot exceed the 2 metres length of my table.

. . . . .

We will now try to apply this numerical example to our problem of an infinity of universes, which, according to Lambert's theory, must exist if we proceed from systems of the first order to universes of the second order, the third order, etc., to infinity. The "series", according to Lambert, is to be regarded as of infinite length. But is it inevitable that the radiation of all its stars upon the little Earth, even if we are certain that the number of luminous systems is infinite, should be, as Olbers tells us that it must be, infinitely great?—In the light of our present knowledge, we can at least conceive that this is not under all circumstances inevitable.—Secondly, is it not thinkable that the infinite number of forces which proceed from this infinite number of universes may under certain circumstances produce a total effect which is *finite*, so that the harmony expressed in Newton's and Kepler's laws

might nevertheless be maintained in the neighbourhood of our Sun?

Charlier shows that we may answer both questions in the affirmative. He proves, in a strictly logical manner, that the *finite* effect of all the stars in all the heavens, and the *finite* effect of all gravitational forces, is guaranteed, even if the universe is, in accordance with Lambert's theory, infinite in extension; *provided only that there is a simple relation between the dimensions of two successive terms of this series of universes.*

The solar system is the first term of our series; a globular star-cluster the second; a Milky Way the third, etc.—How can a fourth term exist, how can a universe of a "higher order", a whole "complex of galaxies" and still higher universes exist, without things happening to our Sun and the planets which are contradicted by our experience?

I will try to explain.—Charlier assumed that the Milky Way contains a thousand million suns; and the square root of a milliard is approximately 31,600.—It does not affect the argument that Charlier's assumption as to the number of stars in the Milky Way was too modest; my intention is simply to illustrate the principle of his calculations.

A universe consisting of Milky Ways can, of course, exist whose diameter is 31,600 times greater than that of our own Milky Way.—This is the general rule: in the succession of individual universes in the "great series" the diameter of each successive universe must be greater than that of its predecessor by a quantity

equal to the square root of the number of the components of this preceding universe. *Then* the starry heavens will appear to us as they do in fact appear; then the planets and comets will revolve in accordance with the calculations of our astronomers. The harmony of the solar system is undisturbed.

So far the theory.—And how does this theory tally with the reality?—Charlier, on the basis of his theory, before he could anticipate the results of later measurements, calculated that the nearest spiral nebulae—such as the nebula in Andromeda—must lie at a distance of 1 million light-years. This estimate is correct. And Hubble's assumption, that the furthest nebulae may be 100 million light-years distant, need not seriously be questioned.—But what are the dimensions of Charlier's whole "super-universe"?—They are of the order of a *milliard* light-years or *ten thousand trillion kilometres* (about six thousand two hundred trillion miles).—Whether it is rational to ask if there can be a universe of an order as much higher than Charlier's universe as this universe is higher than the Milky Way, is a point which we shall consider in our last chapter. According to Charlier, such a universe is theoretically possible if the diameter of the "super-super-universe" is equal to the diameter of Charlier's universe multiplied by "the square root of the number of the existing galaxies". For the time being, however, we will content ourselves with the universe of experience; and here we will summarize the numerical material which brings us close to its limits.

Quite roughly, then, we may say:

The distance of Sirius	is about 10 light-years.
The distance of the stars in the Plough	is about 100 light-years.
The distance of stars of the 10th magnitude	is about 1,000 light-years.
The radius of the "lesser" Milky Way	is about 10,000 light-years.
The radius of the "greater" Milky Way	is about 100,000 light-years.
The distance of the Andromeda nebula	is about 1 million light-years.
The distance of the remoter nebulae	is about 10 million light-years.
The range of the largest telescope	is about 100 million light-years.
The diameter of "Charlier's universe"	is about 1,000 million light-years.

I have intentionally taken certain liberties with these figures. My intention was to give you a striking series of figures which express merely the "order of magnitude" of the distances or universes mentioned.

These are enormous figures, and many a reader may feel that they "make his head whirl". I shall be surprised, indeed, if the beginner has not felt his head whirl before this. Well, if they puzzle him too much, he had better diligently re-read this book from the beginning. If he has done so, he can safely proceed. But I shall advise him to have recourse once more to a diminished scale in order to "see with his own eyes" the number of light-years of which I shall have to speak.

. . . . .

At the Astronomical Congress held in Copenhagen in 1926 I exhibited a sample of my "Table of Dimensions", the object of which is to illustrate as clearly as possible the relative dimensions in the universe. So far only the first part of this table has appeared: a table of dimensions for all relative lengths. On p. 238 is reproduced a small section of this table. The first column gives lengths in kilometres and light-years; the second column gives the number of noughts with which the values given in the first column must be written, if one reckons in centimetres. For example, the number 18 against "1 light-year" means that one light-year, reduced to centimetres, must be written with a 1 and eighteen o's. Without further enlarging on the construction of the table and its various applications, I will merely mention that it contains, in all, five scales or standards, which may be employed to illustrate all the relative dimensions in the universe, from the nucleus of the atom to the universe itself, three being reduced scales for astronomical use, while two are enlarged scales for employment in physics. The "planetary scale" which we have so often applied, and the scale which we employed during our inquiry into the material substance of the stars, in order to "see" an atom, are both taken from this "Table of Dimensions for Length"; and in the near future tables of values for time and mass and pure numbers will appear (*Dümmler, Berlin*).

The five relative standards recommended for use are as follows:

Sub-molecular scale	(1,000 billions : 1)
Molecular scale	(1,000 millions : 1)

1 Billion Light-years 1 Quadrillion km.	30		9	10,000 km.
100 Milliard Light-years 100,000 Trillion km.	29	Radius of curvature of the Universe	8	1,000 km.
10 Milliard Light-years 10,000 Trillion km.	28		7	100 km.
1 Milliard Light-years 1000 Trillion km.	27	ϕ Charlier's Universe	6	10 km.
100 Million Light-years 100 Trillion km.	26	Range of largest telescope	5	1 km.
10 Million Light-years 10 Trillion km.	25		4	100 m.
1 Million Light-years 1 Trillion km.	24	Distance of Nebulae	3	10 m.
100,000 Light-years 100,000 Billion km.	23	ϕ Milky Way (Shapley)	2	1 m.
10,000 Light-years 10,000 Billion km.	22	ϕ Milky Way (Seeliger)	1	1 dm.
1,000 Light-years 1000 Billion km.	21	Distance of Stars of 10th Magnitude	0	1 cm.
100 Light-years 100 Billion km.	20	Distance of Stars in the Bear	−1	1 mm.
10 Light-years 10 Billion km.	19	Distance of Sirius	−2	$\frac{1}{10}$ mm.
1 Light-year 1 Billion km.	18			
$\frac{1}{10}$ Light-year 100 Milliard km.	17			
$\frac{1}{100}$ Light-year 10 Milliard km.	16			Super-stellar Scale 1 : 1000 Trillion
$\frac{1}{1000}$ Light-year	15	ϕ Neptune's Orbit		

Section of the Table of Dimensions by Dr. Oswald Thomas.

Planetary scale	(1 : 1,000 millions)
Stellar scale	(1 : 1,000 billions)
Super-stellar scale	(1 : 1,000 trillions)

Reduced to the "stellar scale", the greater dimensions of the universe, which have hitherto been expressed in light-years, will appear as follows:

Distance of Sirius	1/10 millimetre
Distance of the stars in the Plough	1 millimetre
Distance of stars of the 10th magnitude	1 centimetre
Radius of the "lesser" Milky Way	1 decimetre
Radius of the "greater" Milky Way	1 metre
Distance of the Andromeda nebula	10 metres
Distance of the remoter nebulae	100 metres
Range of the largest telescope	1 kilometre
Diameter of "Charlier's universe"	10 kilometres

. . . . .

We have come to the end of the universe of the astronomers. We will now see what the mathematicians and philosophers have to tell us of the limits, of the "end" of "space".—We are approaching not only the limits of experience, of observation, but also the limits of our comprehension. But before we little human creatures venture on such an extension of the scope of our mind and senses, before we take this last step of all, let us turn back awhile and consider how the Earth itself originated, from whose dust we have arisen. Under what circumstances was this little globe of ours born?

CHAPTER IX

THE GENESIS OF THE EARTH

It is a fine sunny day; a may-fly wings its way over the roofs of the city, and in the evening, which is also the evening of its life, it comes to rest far out in the country. We will imagine that our may-fly has intelligence and a scientific habit of thought. It has been interested by the sight of the "men" whom it has seen in its flight over the streets of the city. It has taken a good look at all the people, and in particular it has noted their size. Some were tall, some were short, many were quite small, while others were considerably above the ordinary stature. The may-fly speculates as to how these people, each of whom is a separate individual, come into existence, and what is their method of development. It has never been able to follow the development of any one person, for it has only lived one day, and its observations of human beings were limited to a few hours. From spatial juxtaposition, from the images which it has perceived of individual persons, walking together through the streets, it will, inevitably, evolve a temporal succession. Thinking of all these people of different statures, it conceives the idea, which seems to it only rational, of arranging them in the order of their dimensions, and thereby it arrives at the following conclusion: Men pass through the following stages of development; —they are first quite small, then they become larger, then they reach a medium size, and finally become

very large. We see that on the whole the may-fly has hit on the right idea. But, if it is a conscientious may-fly, when it comes to write its chapter on the "cosmogony of human beings" it will not present its "discovery" as an inexpugnable dogma, but merely as a hypothesis.

The wife of our may-fly is greatly interested in the hair of these human beings. She has seen some with black hair, and others with yellow, brown, or white hair, and if she too has a scientific mind she may deduce the following theory of evolution: the most natural order of succession of the colours observed is from light to dark—that is, from white to black—and she assumes that human beings, in the course of their development, have first white hair, then yellow, and then brown, then dark brown, and finally black. We may smile at this simplicity, but only until we remember that relatively to the vast universe, the stages of whose development are measured in millions of years, we ourselves are no more than may-flies.

. . . . .

How did the Sun originate, how the Moon—and how the Earth? Apart from a few such phenomena as—for example—shooting stars, the changes in the superficial layer of the Sun, or the appearance of "novae", we find, throughout the universe, almost without exception, only such changes as need, for their accomplishment, periods of time so vast that compared with these the few hundreds or thousands of years of scientific observation and human history are no more than a

moment. Relatively to the universe we are, indeed, creatures of a day. And if we should attempt a cosmogony of the universe, we shall find that there is only one method of procedure open to us. It is the method followed by our may-flies: from spatial juxtaposition we must try to deduce a temporal succession. It goes without saying that all our speculations are merely hypothetical in character, and we can only judge of the value of our hypotheses when we see how far they are in agreement with experience—with our observations.

. . . . .

Every people in the world has its fables of the origin of the Earth, and the creation of the Sun and Moon. The nature of these naïve cosmogonies depends on the concrete image which men have formed of the structure of the universe in general. If the whole firmament was nothing more than the back of a great tortoise, over which the Sun or the Moon went wandering, it was naturally assumed that the origin of the universe was similar to that of a tortoise. Once upon a time there was a great egg . . . and so the story proceeds. But another tortoise must have laid this egg!—Even when we come to scientific hypotheses the problem of the origin of the universe is closely bound up with the opinions held as to the structure and (above all) the dimensions of the universe. A couple of centuries ago the astronomers had exact knowledge of the Sun, the Moon, and the planets, and beyond these of the comets and meteors. The "universe", into whose origin they

sought to inquire, came to an end, physically speaking, with the limits of the planetary system. Concerning the universe of the fixed stars, little was known beyond their numbers, their apparent brightness, and their movements in the heavens. They were still little more than points of light on the spherical firmament, concerning whose physical constitution nothing whatever was known.

There were in those days no photographs of the heavens, whereas to-day photography has revealed the very finest details of the structure of all manner of heavenly objects; there was no stellar photometry, whereas to-day, by means of photo-sensitive cells, we are able to distinguish more than a hundred stages of brightness between stars of the second and the third magnitude; and there was no bolometer—which may literally be called a "telescopic thermometer"—to measure the radiation, and thereby the temperature, of the stars, even at distances of millions and billions of miles. Even the ordinary spectroscope, which enables us to detect the different chemical elements in the distant stars, was not applied to astronomy before the year 1860; while the modern physical methods which constitute the very alphabet of astronomy were as yet unimagined.

. . . . .

The best-known cosmogonies of the time—those of Kant (1755) and Laplace (1796)—reflect the scientific knowledge and resources of their age.

Kant, the philosopher, who never travelled beyond

the walls of his native city, knew this Earth of ours as though he had explored it. He was never an astronomer, yet he not only wrote a philosophical treatise on the origin of the Sun and the planets, but he also produced a purely astronomical work, the *General Natural History of the Heavens, or an Essay on the Constitution and the Mechanical Origin of the Whole Structure of the Universe.*

Kant assumes that the primal condition of our planetary system was a vast cloud of cosmic dust, whose circumference was greater than that of the planetary system. This primal matter consisted of innumerable particles, of differing mass, and moving at different velocities; flying in all directions in obedience to no observable law, and with no directional tendency—in short, a true chaos. The only thing which Kant assumed was a slow rotatory movement, whose first appearance the philosopher did his best to explain. The rotation of the cosmic cloud led to the flattening of the whole system, whose outer portions cohered into individual fractions, from which the planets, including the Earth, derived their origin. The action of gravity not only shaped the planets, but gave them the heat which inhered in them even while cooling. The concentration of the preponderatingly large remaining mass at the centre of the system gave rise to the Sun.

Laplace, in his *Explanation of the System of the Universe*, assumed, in the place of Kant's cloud of cosmic dust, a nebular mass of matter in a gaseous condition. Laplace's primal nebula had about the same dimen-

sions and the same form as Kant's dust-cloud. It rotated, and threw off regular rings, which revolved about the still contracting nucleus. These rings broke and contracted, forming the outer planets, and finally the Earth, Venus, and Mercury; and the satellites of the planets were formed in the same way.

. . . . .

The cosmogonies of Kant and Laplace, greatly as they differ in respect of the hypothetical primal matter, and despite their defects, have to this day been the parents of all serious subsequent cosmogonies. The great astronomers have, almost without exception, subscribed to one or the other, and Laplace's "nebular hypothesis" in particular has been in many respects improved or modified by eminent mathematicians. The classic cosmogony of the present day proceeds, generally speaking, in the following manner: It subjects some kind of cosmic formation, as, for instance, a Laplacean nebula, which is assumed to be a sphere, or perhaps an ellipsoid of rotation, to mathematical treatment; and the mathematicians inquire what mechanical and dynamic conditions must obtain if the nebular figure is to exist for a very long period without collapsing. Individual forms are examined in respect of their stability. If such stable forms are found, the conditions are then sought under which one form may evolve into another. It goes without saying that this classic method of investigation, which involves the most abstruse and difficult mathematics, can proceed only very slowly, and that it is scrupulously careful

to avoid all assertions which might by any means be regarded as speculative.

. . . . .

Patience is the greatest virtue of the astronomer; yet it must not be taken amiss—since the longest life is so short—if our scientific curiosity is not always quite contented with these slow and laborious methods. The new ideas of scientific thinkers are like a fresh breeze in the monotony of our existence. We will therefore venture to outstrip the results of the classic cosmogony, and listen to the views of a thoroughly modern scientist.

Professor J. H. Jeans has advanced a new hypothesis of the origin of the solar system, whose main features I will try to summarize.

. . . . .

The telescopic heavens are full of wonders. Let us see whether we cannot arrange the many forms discovered in a series. Any one form in this series must be so constituted that we can without difficulty imagine it as arising out of the form immediately preceding it; and the last members of this series of forms must be our Sun and our Earth.

That our Sun is a ball of gas no one doubts to-day. That our Earth was created out of the substance of the Sun—that it is a child born of the womb of the Sun its mother, or at least that it and the Sun were born of the same primal nebula—is now generally accepted.—If we wish to find among the bodies visible in the heavens the ancestral forms of our solar system,

we will first of all pass in review those structures known to the astronomers as nebulae.

For example, there is the "crab nebula", of which I have already spoken; there is also the "veil nebula" in the Swan. In the same constellation there is a second interesting gaseous nebula. It has been photographed by Max Wolf of Heidelberg, who has named it "the America nebula". The contours of this nebula justify its name. The best known of all the irregular gaseous nebulae is in the scabbard of Orion, under the three stars of the belt. It is so extensive that the whole constellation shows traces of its offshoots. Its brightest portion is, of course, visible to the naked eye, and if we examine it through the telescope we perceive, running into the bright mass of the nebula, a dark inlet known as "the Lion's Mouth". In the Lion's Mouth are four small but intensely bright white stars, the "trapezium" of the nebula. It looks as though the bright nebulous matter which once filled this inlet had contracted, leaving a "stellar vacuum" in the neighbourhood of the stars of the trapezium, and as though the stars themselves were a sort of condensation-product of the nebular mass.—The stars in general, therefore, must be directly derived from the often grotesquely shaped nebulae surrounding them.—This was the conception which might very well force itself on the superficial observer, and which, for that matter, was current in astronomical circles.

To-day we know that it is not the white stars, but the very red stars which represent the first phase of stellar evolution. And it must not be assumed that our

most important star, the Sun, can have formed itself out of such an ordinary irregular nebula. The examination of the irregular nebulae from the cosmogonic standpoint does not encourage this hypothesis. With the best will in the world no series of forms can be constituted, beginning with such nebulae, which could be regarded as an evolutionary series.

Jeans passed on to the regular nebulae (Fig. 25). To begin with, in addition to the perfectly globular nebulae there are some which have been catalogued, by reason of their contours, as spindle nebulae. They

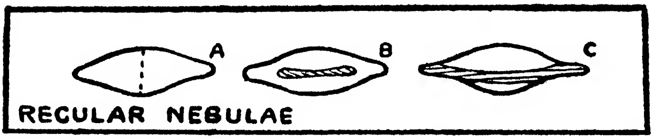

FIG. 25.—Regular Nebulae: incipient Stages.

are long spindle-shaped nebulae with pointed ends; they are really lens-shaped, or lentiform, but we see them edge on. Spectroscopic observations have established the fact that these "spindles" rotate about an axis; that one of the points is moving towards us, while the other is moving with the same velocity away from us. The whole body is rotating about an axis, which in Fig. 25 A is represented by the dotted line. Jeans assumes that these spindle nebulae represent a very early stage in the evolution of the masses from which whole universes of stars derive their origin.

At first, in all probability, there were only great globular nebulae, which might form themselves directly

out of the atoms of matter present in the universe. Fortuitously, so to speak, since the mutually attracting and contracting materials of the nebulae were not distributed with absolute uniformity, the whole began to rotate. Centrifugal force would change the globular mass into a lentiform nebula. Such a nebula, seen "edge on", is represented by A, Fig. 25. This nebula is one of many similar forms, while those shown at B and C are likewise of frequent occurrence. These are typical forms. B may represent a stage of evolution following upon A. An "equator" becomes visible, shown (in schematic form) as a dark seam, which in C becomes a definite band or rim.

The matter flung out into the periphery of the "lens" is most exposed to the cooling effect of cold interstellar space. The continuous loss of heat by radiation into space results in the cooling of the outer mass, so that a sort of ring forms round the entire "lens", which completely absorbs many of the light-rays proceeding from the centre.—That such equatorial bands exist even in cosmic systems was demonstrated by Charlier in respect of our own Milky Way. He showed that it is precisely in the plane of the galaxy that the distant spiral nebulae are invisible, which can be explained only by assuming the existence of an absorbent belt which surrounds the extreme borders of our own Milky Way.

Further types of spindle nebulae show conspicuous bright clots in the dark equatorial belts. These give one the impression that the material of the belt is slowly gathering itself together to form stars or star-clusters.

The figures A, B, and C show the nebulae as seen from the side. But it goes without saying that the axis of rotation is not always at right angles to the line of vision. These nebulae are scattered all over the heavens, in all sorts of positions, so that there are narrow elliptical nebulae, broad elliptical nebulae, and finally nebulae on which we "look down", so to speak: that is, nebulae whose axis of rotation coincides with our line of sight. In these elliptical and circular nebulae we find very numerous clots or condensations which should evolve either into individual suns or, more probably, into clusters of suns.

The schematic outline of a spiral nebula (Fig. 24) shows us, of course quite approximately, the elliptical form of a universe in an advanced phase of evolution. The clots and condensations are omitted, but the sketch shows us the arms or spokes which spring from the actual nucleus and lie wrapped spirally about it. We must assume that tidal action has caused the nebular mass to stream outwards in two diametrically opposite regions, and that the two outpourings of nebular matter, retaining the original rotation of the whole system, have assumed the form of spiral spokes.

All the spiral nebulae, accordingly, are to be regarded as representing the last phases of the evolutionary series which began with the simple structureless "spindle". According to this theory, the Andromeda nebula and the nebula in Canes Venatici are already completed universes. In their arms, or spokes, as we have seen, individual stars can be distinguished, so that we seem to have cogent proof of the gradual derivation of the

stars, through typical cosmic forms, from the crude mass of the simplest "spindle-shaped" nebulae. And if these conclusions are accepted, we shall be in a position to explain how our own Sun may have originated. But before we proceed any farther we will inquire rather more closely into the state of the spiral nebula *before* it begins to form individual stars.

. . . . .

The spiral arms are no more than skeins of gas in the vacuum of interstellar space.—Readers who have some technical knowledge will possibly shake their heads, and reply—correctly enough—that laboratory experiments, and practical experience, invariably show that any quantity of gaseous matter, of whatever kind, if released into a vacuum, immediately expands into this vacuum until the new space is uniformly filled with the rarefied gas. It is unthinkable that definitely delimited "skeins of gas", like the spiral "spokes" of the cosmic forms of which we have been speaking, could really exist.

And this is the reply to their objection: The molecules of the gaseous masses handled in the laboratory mutually attract one another in accordance with the universal law of gravitation, but their total mass, even in the case of a considerable volume of gas, is so small that any demonstrable tendency to agglomeration is quite excluded. The masses of gas handled in laboratory or factory are too small for that. On the other hand, the spiral nebulae and their "spokes" are universes of stupendous extent, beside which all our technical

dimensions are reduced to nothingness. In the case of masses so enormous as those which we assume of the spiral nebulae, the internal forces of gravitation are so great that the molecules of gas are coerced into obedience even before the gaseous masses of the nebulae have begun to agglomerate into the denser masses of nascent suns and star-clusters.

Jeans has undertaken some interesting researches in respect of the density of the matter in the spirals of the spiral nebulae.—Let us imagine a large room from which, by means of some magical air-pump, after hermetically closing the doors and windows and the pores of the walls, floor, and ceiling, we have absolutely removed all the air, down to the last molecule, so that the vacuum is perfect. Into this room we introduce an electric lamp, or a "wireless" valve, from whose bulb the gas has been exhausted by an ordinary mercury air-pump. We break the bulb; the rarefied gas rushes out and fills the whole room, completely and uniformly.—Well, the atmosphere, or rather the imperfect vacuum in the room, is something like *ten thousand times* denser than the nebular matter in the densest part, in the nucleus, of the spiral nebulae.

. . . . .

It may very well seem that, broadly speaking, the explanation just offered of the origin of cosmic bodies does not essentially differ from Laplace's hypothesis. Fundamentally, of course, Jeans' explanation is a nebular hypothesis; but we must not forget the grotesque difference between the respective sizes of

the "primal nebulae". We must realize that if one of Jeans' cosmic nebula were reduced to our "stellar scale" of 1 : 1,000,000,000,000,000, it would cover a good part of Europe, while the whole "primal nebula" of Laplace would shrink to the size of a penny. The two hypotheses, the old and the new, have little more than a nominal relationship. In each case we call the primitive body the "primal nebula", but the two are fundamentally different.

. . . . .

We may therefore believe that our Sun, with thousands and millions like it, was born of a vast spiral nebula; and we shall be even more inclined to believe this if the scientists should prove, as it seems that they may, that the lesser, or perhaps the greater Milky Way, of which the Sun is only a particle, still possesses a spiral structure. Its further development could then proceed without any such collision as we have imagined might be the origin of a star. We have already seen that the Sun was once an F-star, and is now a G-star on the down-grade of its evolution.

It might seem that we should be equally justified in imagining the derivation of the planets from the substance of the Sun as a repetition in miniature of the process just described. The Sun might be constrained, by the rotation imparted to it at its birth, to part with the masses out of which the planets, and with them our Earth and Moon, would be formed.

The fundamental hypothesis of this assumption would be that the planets should move in a plane at

right angles to the axis of rotation of the Sun. Strangely enough, this is not the case. The planets, apart from small divergencies, move in one and the same plane, but this plane forms *an angle of seven degrees* with the plane of the Sun's equator. This deviation of seven degrees is inexplicable if we maintain that the planets were merely flung out of the body of the Sun. There is nothing left for us but to seek a prime cause outside the planetary system.

. . . . .

Our Sun and its neighbour stars form a regular star-cluster (Fig. 12). For reasons of conveniences, the Sun has been placed in the centre of the sketch, and circles have been described about it as a centre whose radii represent five, ten, fifteen, and twenty light-years. In the space thus divided are shown the stars in the neighbourhood of the Sun. One comparatively near star is Altaïr in Aquila: still nearer is Procyon in Canis Minor, while Sirius lies at a distance of nine light-years.

It was long believed that the fixed star nearest to the Sun was Alpha of the Centaur, whose distance is about four and a third light-years; but one has been found still nearer, in the immediate neighbourhood of Alpha. It is known as Proxima Centauri—the "nearest in the Centaur".—If any disturbance occurred from without, one of these neighbouring stars might very well be held responsible. It may be that Proxima Centauri set up such a tide in the Sun as would explain the origin of the planets.

Even the little Moon produces perceptible effects upon the Earth, and the seas are lifted in tides which attain a height of several feet, and in some places of many yards. Mathematical calculation informs us as to the possible effect of an Alpha or Proxima Centauri. —Take the millionth part of a centimetre, and again the millionth part of this millionth part, and a percentage of this will give you the maximum "height" through which the atmosphere of the Sun could be lifted by the action of this neighbour star.—No, we have *not* found the midwife of our Sun!

. . . . .

But I have, with intention, omitted a certain fact. The stars, of course, are not in a state of rest relatively to one another. It may be that at one time some star was much nearer the Sun. But we have already seen how rarely two stars can collide or come into close proximity—simply by reason of their extraordinarily sparse distribution in space. Once again, it seems, we are at a loss.—Yet there appears to be a possible solution.

At the time when the planets came into existence, or, rather, when they were beginning to form themselves in the as yet unconsolidated mass of the Sun, the whole spiral nebula to which our Sun and its neighbour stars owe their existence was by no means so far divided that the spheres of influence of the mass which was later to become our Sun and the masses of the incipient neighbour Suns were definitely separated. It is therefore quite conceivable that two adjacent

systems which were still, so to speak, hanging on to one another (our solar system being one of them) might set up such a mutual tidal action that a certain amount of material might be, as it were, sucked out of the solar mass, thereafter to form itself into planetary globes. According to this hypothesis the birth of the planets must have been a rapid process: rapid, that is, relatively to the vast period of time which the great primal nebula required to increase its circumference, by mere centrifugal action, to that of a wide spiral universe.

We unwind a thread from a reel. Our hand describes a spiral path, and it is a very long time before we have unwound even a part of the reel.—Now imagine yourself firing a torpedo. It rushes on its way at a very high speed.—The time taken to unwind a reel of thread might be compared with the time required by an ellipsoid of rotation gradually to expand itself into a spiral universe, while the ejection of the planetary masses from the body of the Sun might be compared with the firing of a torpedo.

. . . . .

There is no reason why we should not give this solar projectile the form of a torpedo—thick in the middle and pointed at either end. For the sake of simplicity, we will imagine that the mass out of which the planets were formed had very roughly such a shape. The total mass of the planets was present in this projectile, and out of it the eight great planets were formed, including our Earth.

We assume the existence of this solar torpedo: a mass shaped like a Zeppelin or a fat cigar; at all events, much wider and more massive in the middle than at the ends. If the planets are to form themselves out of this heated mass, it is evident that the larger planets will be formed in the middle, and the smaller ones at the ends of the torpedo.—We will arrange the eight planets, from Mercury to Neptune, in a row, and in the actual order of their distance from the Sun (which

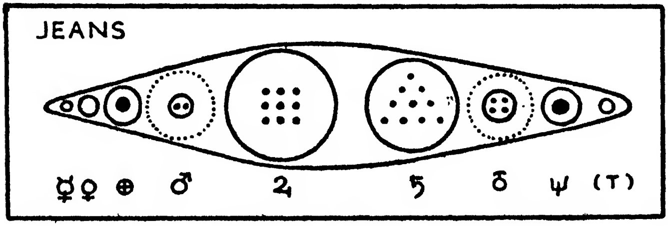

Fig. 26.—Arrangement of Planetary Masses.

we imagine as being far away on the left). The larger planets are actually in the middle of the series, just where our torpedo is most massive, and the comparatively small planets are at either end.—If there is a "Trans-Neptune"[1]—and the paths of these comets which have very long orbits do seem to point to its existence—it would undoubtedly be very small, and would fit quite comfortably into this frame.—But there is something more to be considered.

Let us count the moons of the individual planets. One has a number of moons; another has one; Mercury and Venus have none. We may imagine the moons to have come into existence in much the same way

[1] See footnote, p. 128.

as the planets, or we may prefer to think that they were flung off by centrifugal force. However this may be, one thing is certain: that only a body like Jupiter or Saturn, which stands in the middle of the whole series, and consequently possesses a very large mass, and above all a great store of heat, would be capable of throwing off a large number of moons.—In this schematic diagram, then, which I reproduce with all reserve, the planets in the middle portion of the planetary projectile should be rich in moons, while those at either end should be poor.—The moons are indicated by black dots; a small dot indicates a moon which is small compared with the planet, and a large dot a moon which is relatively large; and we see that the hypothetical rule is confirmed by the facts: Jupiter and Saturn have nine and ten moons respectively; and at one end of the series we have the moonless Mercury and Venus. The problematical Trans-Neptune[1] should likewise be moonless. Between the ends and the middle of the series are the planets, which, like Mars and Uranus, have only a few moons, or, like the Earth and Neptune, only one, but that a comparatively large one. The dimensions of Mars and Uranus show divergences from those demanded by our scheme, which are denoted by dotted circles. Jeans, however, has furnished an explanation of this apparent discrepancy, and also of the arrangement of the densities of the various planets.

Our Earth, then, was born of the womb of the planetary mass. It did not receive a very great portion

[1] See footnote, p. 128.

of this mass for its inheritance, since Jupiter and Saturn appropriated the greater part. The incandescent Earth —as we read in the chapter on the Moon—was torn in two by centrifugal force; but, since it possessed no very great store of heat, the outer stratum of the globe congealed soon after the birth of the Moon—at all events, too quickly to permit of another such parturition.

. . . . .

There is much that is attractive in this hypothesis, and we may possibly find that we shall have to accept it as the correct solution of the problem. There is, at all events, no doubt that it indicates a direction in which further research may be undertaken. Jeans's hypothesis has been assailed at many points, and it certainly has its defects; but Jeans himself is not one of those rigid thinkers who thump the table and refuse to budge. He is as elastic in his ideas as modern science is in its methods. This is an age of mighty revolutions, even in the province of cosmogony. We should be the last to hold Jeans's hypothesis as the only possible explanation. We should rejoice that he who is striving for knowledge of the actual processes of Nature may still hope for many a wonderful revelation.

"I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."—Newton's words are still true to-day.

CHAPTER X

"WHERE DOES THE UNIVERSE END?"

MY study has a certain length, a certain width, and lastly a certain height. Length, breadth, and height: these three concepts are what we call the three *dimensions* of the room. The book you are reading likewise has three dimensions. If you lay it closed upon the table you will find, perhaps, that it is eight inches long, five inches wide, and an inch and a half "high", or thick. And how many dimensions has the whole universe, the *real* universe? Has it also three dimensions? To this question we shall try to find a satisfactory answer.

In the case of the human body we are accustomed to speak of height and breadth, and by height we understand the distance measured between the crown of the head and the sole of the foot, and by breadth the breadth across the shoulders; while for the third dimension we might take the distance between two sliding-doors set just so far apart that the person whose "dimensions" we are investigating could slip through without squeezing the breath out of his body.—And similarly every body, even a spherical body, like the astronomical globe in my library, has three dimensions or "extensions", whether we call them length, breadth, and height, or represent them by other names and symbols.

. . . . .

The book on the table is three-dimensional. Now

consider one of the pages of the book: how many dimensions has it? Perhaps some wide-awake reader will say that this also has three dimensions, and he is, of course, quite right, for he realizes, as we do, that the thickness of the paper must not be ignored. But now we will imagine an infinitely thin paper, in respect of which it would be as absurd to speak of thickness as it would be to pour a bucket of water into the Black Sea and assert that one had thereby raised its level by a certain amount. Such a sheet of paper, then, has only length and breadth; it is a two-dimensional form, and we are still to regard it as two-dimensional even if we bend the paper. Similarly, we shall regard the edge of the page as a one-dimensional form, having only length, and neither breadth nor thickness.

Three-dimensional, two-dimensional, one-dimensional! Perhaps there is also a no-dimensional object!—But instead of "object" we will say simply "figure", since this is the term usually employed in plane geometry. Well, we have a no-dimensional figure in the *point*, of which we have been taught that it has neither length, nor breadth, nor thickness. "It is an angle with both the sides taken out." I do not know a better and more lucid definition.

And now—another imaginary example! We will suppose that I have before me a cube of an ideally accommodating material, absolutely plastic, and also compressible and extensible at will. I will call this material "geometrite". I place the cube on the table. This cube has three dimensions. Now—and remember, this is only an imaginary experiment, a sort of intel-

lectual game, though in the end we may learn a good deal from it—I subject my cube of geometrite to a downward pressure until I obtain a square of geometrite, which has length and breadth, but no thickness. It has only two dimensions; as a result of my violent treatment of the cube one dimension has been simply annihilated. Now we will imagine that I take this infinitely thin surface—thin as a breath of vapour or a film of dust on the table—no, we have squeezed it a thousand million times thinner than even a film of dust—and I compress it laterally until the two-dimensional figure has become a line, a one-dimensional figure. Once more a dimension has been "lost"; and lastly, if I compress this line in its own direction until it is only a point, I have turned the one-dimensional figure into a no-dimensional something, so that even the last dimension has disappeared.

And now—as conjurers do—I will not only perform the "vanishing trick"; I will try to "produce" something.—I will take such a "pointful" of geometrite, of this ideally plastic and ductile substance, and I will draw it out like a bit of chewing-gum. The point acquires *one* dimension: it becomes a thread, a line. Now, in imagination, I will iron out this thread, which has no breadth, until it has become a broad band. I have now given the one-dimensional form a second dimension; and lastly, by pulling at this infinitely thin plate as though I were opening an opera-hat or extending a concertina, I can—in imagination!—convert it into a three-dimensional solid.—Each time I am adding one more dimension to those which the

form already possesses; the one-dimensional form acquires two dimensions; the two-dimensional surface becomes a three-dimensional volume; and the three . . . But stop! What would happen if I tried to add yet another dimension to the three-dimensional volume?

"It can't be done!" We all know that. But we will be bold, and we will at least give a name to the form, or whatever we like to call it, which results if yet one more dimension is added to length, breadth, and height: we will call it four-dimensional. We shall not hesitate even to speak—after this little explanation—of a "four-dimensional space" or a "four-dimensional body".

. . . . .

But now I am going actually to *show* you such a four-dimensional body. It is not an animal, which instead of one-dimensional hairs has two-dimensional scales hanging from its body, and in which the two-dimensional surface of the forehead is replaced by a cumbrous cube, and so forth. You are going to see—and you will feel no surprise or alarm—a four-dimensional something with your own eyes; you may take this precious rarity in your hands and examine it as closely as you will.

But, first of all, permit me a brief digression. May I take it that you have never in your lives seen the palace of the Dalai Lama? But you are quite satisfied that it exists, even though you have never seen the real thing; for you have at least seen it in photographs. Well, let us look at such a photograph. There is the authentic palace of the Dalai Lama—only in

its representation on the two-dimensional photographic plate one of the dimensions of the palace has disappeared. Yet you will not complain that we are able to perceive only an "image" of the palace. But this photograph is an image, a projection, a two-dimensional projection of a three-dimensional body. How would it be, then, if I were now to endeavour to show you a projection or image of a four-dimensional body? This projection must have one dimension less than four—and here you can actually see with your own eyes such a "projection of a four-dimensional body". Here, for example, is . . . a piece of chalk, with which I have been drawing on the blackboard.

A sensational object, this piece of chalk! It is something that you have never seen before—"the image of a four-dimensional body". Yet to us it looks as ordinary as though we had been looking at such things all our lives.—Well, as a matter of fact, we can call any ordinary object that has length, breadth, and height "the image or projection of a four-dimensional body". There is no law that forbids us to do so.

And yet, of course, it is only a figure of speech; we cannot with the best will in the world really *imagine* a space of four dimensions. And why?—We do not know; but we may try to "explain" the matter by the formula: "because we human beings are ourselves objects of only three dimensions"—just as are the houses in which we live.

. . . . .

Before we clamber out of our actual world into a

"fourth dimension", as we shall presently be compelled to do, we must, for the moment, turn our thoughts in another direction; and now that our imaginations have been to some extent prepared by the foregoing explanations we ought not to find this difficult.

Let us imagine, as Helmholtz suggested, that there are somewhere in the universe "men" or animate beings who possess not three, but only *two* dimensions —length and breadth; like the paper dolls a child cuts out with a pair of scissors. But we must imagine that these paper dolls are highly intelligent; they have all the intellectual faculties, and every sort of technical knowledge. There is only one thing which these beings cannot do: they cannot imagine a third dimension. They are philosophers; they rack their brains over all sorts of essential and unessential things; but there is one thing, as we have seen, that they absolutely cannot do: imagine a third dimension; even though they know that 0 is followed by the figure 1, which in its turn is followed by the figure 2, which corresponds to the number of their dimensions, and that 2 is followed by 3, and so on.

Since our flat beings are highly intelligent, they will be perfectly well aware that the world and the universe in which they live are likewise two-dimensional. This is a matter of course, "for there is no such thing as a third dimension".

. . . . .

For thousands and thousands of years men believed our Earth to be flat; and if the globe had been, let

us say, ten thousand times as large as it is, while the conditions of life remained unchanged, it is possible that the idea that the Earth must be round would never have occurred to us. Of course, from the appearances of the stars, which have taught us so many things, and have even revealed to us the shape of our Earth, men of exceptional faculties might have deduced that the Earth is a sphere.—But we may imagine not only that our Earth might have been ten thousand times larger than it is, but that a perpetual London fog might have lain over the whole surface of the Earth since the first beginnings of life. Under such conditions it is quite conceivable that we should still be speaking of "the terrestrial disc". The "curvature of the Earth's surface" would be an impossible phrase.

. . . . .

With our superior understanding—which, unless badly disordered, is certainly three-dimensional—let us now observe our "two-dimensional beings". They live in a "world" of their own; for so they call the area in which they have their being, and in respect of which they deduce their philosophies. This "world" of theirs, we stipulated, must be flat; flat as we conceive flatness, a "two-dimensional plane surface", like the surface of the table-top, for example, but as much bigger as you like to imagine it (Fig. 27). The flat beings are thoroughly enterprising; they move about their world, which they, as a matter of course, regard as two-dimensional, and undertake journeys and voyages of exploration in all directions; suffering, perhaps, the

same privations as our Polar explorers, and returning at last to their original starting-point M. That they consider the world to be flat goes without saying; it would never occur to the cleverest of them that it was or *could* be anything else. Among the flat beings there are, of course, expert geographers. They make maps of the different countries, and charts of the whole world, and round the expanse of "Earth" which has been visited by their explorers they draw a circle—in our figure the closed circle A—B—C. The surface of this circular area might be described as "the world

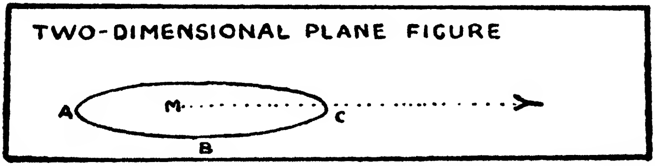

FIG. 27.—Two-dimensional Plane Figure.

of experience", or "the known world". And the circumference of the circle represents the extreme limit of this known world. The distance from M to C is "the radius of the known world".

In this two-dimensional world there are not only geographers, but also philosophers, who want at all costs to determine what the "universe" is like outside this boundary. In all probability they won't puzzle their brains very long. They will say: "Our two-dimensional universe extends to infinity in all directions; it is infinitely great. There is no end to it in any direction."

Just as we do, they speak of the infinity of the

universe, but for them, as for us, this "infinity of the universe" is only a sort of narcotic for questioners. For we cannot *imagine*, we cannot conceive such an infinity. But the flat beings know of no way out of the difficulty, and they formulate the axiom: "The universe in which we live is infinitely great, and the length of its radius is infinite."

For the rest, our flat beings study all sorts of sciences. They construct triangles, and they find that the sum of the three internal angles is *always* 180°, or two right angles. Then they describe circles of all possible dimensions, and measure their circumferences and diameters, and they find that the circumference is *always*, without exception, 3·14 times greater than the diameter, which is simply the straight line joining two points of the circumference which passes through the centre of the circle.

. . . . .

Here is a second example; "a two-dimensional spherical figure"! (Fig. 28.)—We will assume that our flat two-dimensional beings inhabit a world which is two-dimensional in the following sense: we will imagine it to be situated on the top of the sphere No. 1 in Fig. 28, and to resemble the top of an egg-shell; but it is so shallow that it is impossible to measure its depth in any way. We can then say that this shell is a two-dimensional form, which at any point of its surface extends only in two directions, "along and across", but that it is spherical: that is, it appears to *us* as spherical.

And in this two-dimensional world there live, as before, two-dimensional beings. The whole world is so large that these flat beings, in the whole course

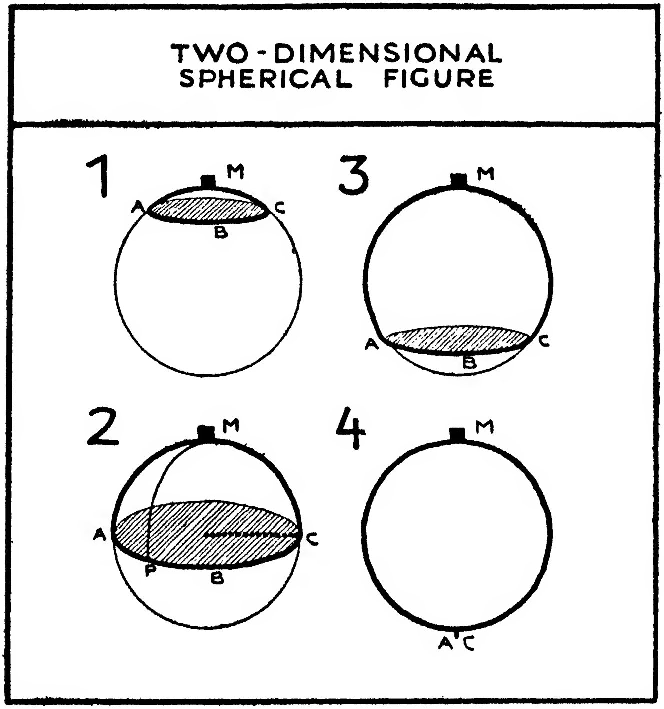

FIG. 28.—Two-Dimensional Spherical Figure.

of their history, have been able to acquaint themselves with only a portion of it. At the cost of endless sacrifice they have explored a portion of the world whose circumference is marked A—B—C in the figure. (And

it must, of course, be remembered that this "world of experience" is not the shaded circle, whose plane surface lies quite outside the world of the two-dimensional beings, but the section of spherical surface whose diameter is A—M—C.) This world is, according to our ideas, visibly curved; it is spherical. But how will the flat beings, who cannot possibly conceive of a curvature of their two-dimensional world, define this world of theirs? They will say that it is a great circle, a flat disc.

On their voyages of discovery they may perhaps penetrate so far that they extend their "world of experience" to the circle A—P—B—C (Fig. 28, 2). Will it now perhaps occur to them that their world may be spherical?—No; for they are convinced of their own two-dimensionality, and of the two-dimensionality of space and of the whole universe. Indeed, we must not give them credit for being able to imagine such a thing as the shaded circle A—P—B—C, since this would mean that they were stepping out of their two-dimensional world, that absolutely thin shell. And this would be entirely contrary to our original hypothesis, that the world of these curious beings is effectively two-dimensional, a mere shell without thickness.

We will now make another hypothesis. We will assume that the flat beings are able to reach even the line A—B—C (Fig. 28, 3)—but that they are never able to get as far as A C (Fig. 28, 4). We are to suppose that it is as impossible for them to reach this point as it is for us to drive a tunnel to the centre of the Earth.

But there are mathematicians among these two-dimensional beings. These mathematicians explore the world they live in, draw circles and triangles, and make measurements. Working over their drawing-boards, they find that the sum of the internal angles of a triangle is positively 180°, and that the circumference of any ordinary circle is 3·14 times the diameter.—But some intuition tells them that this drawing-board geometry is not wholly satisfactory. They wish to see whether these two propositions concerning the circle and the triangle hold good in the case of very large figures, in which any possible error of calculation will be more apparent.—And one day it occurs to them to draw the biggest of all possible circles, just where their explorers have planted their two-dimensional flags and flag-staffs, to show those who may follow them how far they have pushed the frontiers of the known world. At the cost of effort and sacrifice and pecuniary expense they draw the circle A—P—B—C, and measure its circumference. Then—and this they find somewhat easier—they measure the diameter A—M—C of this circle (of what we three-dimensional critics recognize as a hemisphere, though the ordinary folk among the flat beings believe it, as a matter of course, to be a flat circular disc). To their amazement, this is what they find: the circumference of this great circle is *not* 3·14 times as great as the diameter, but is only twice as great. The geometry which they have always held to be infallible suddenly proves to be erroneous, and is always erroneous in the case of very large circles. Intrigued by this experiment, the mathe-

maticians of the two-dimensional world now proceed to measure a very large triangle. They take the triangle A—P—M which is, of course, believed to be perfectly flat—and measure its angles. The angle at A measures 90°—that is to say, it is a right angle; and the angle at P is likewise a right angle; so that the two together give the mathematicians the two right angles which a triangle must contain, and the 42°—let us say—which they find at M constitutes a very conspicuous surplus over the usual 180° which, according to drawing-board geometry, is the constant sum of the internal angles of a triangle.

Now, since the geometry which they have hitherto practised does not hold good either for the circle or for the triangle, another geometry must be invented, a "universal" geometry, which must hold good for all figures, large or small.—And so the mathematicians among the two-dimensional beings—that is, the more brilliant of them—proceed to create a new, universal geometry, a geometry which, not content with the two dimensions of experience, summons to its aid a third, unimaginable dimension. Now, if, in their two-dimensional world, a one-dimensional line refuses to run straight ahead, but turns to the right or left—that is, if it runs not only in the "length-direction", but also in the "breadth-direction"—in other words, if it requires "one more dimension than it is allowed" (figuratively speaking)—the mathematicians will say that it is *curved.* In like manner, when to the known two dimensions of their world they have to add another dimension, they decide that they will have to call their

world and their space "curved", though they will be quite unable to imagine its "curvature", nor will they try to do so. Nevertheless, by means of the excess over the 180° of the normal triangle they are able to devise a means of measuring the curvature of their world, and are even able to calculate the length of the "radius of the curvature of space".

This "radius of curvature" will have a definite meaning for them, though they will be quite unable to imagine it; for in order to conceive of the sphere represented in Fig. 28 they would have to be able to form a clear idea of a third dimension in addition to the two in which they have their being. For us three-dimensional beings this third dimension is demonstrated by the fact that we perceive their two-dimensional world or universe—and to them it is "the universe"—as round or "spherical".

We are able without more ado to call the dotted line in Fig. 28, 2, the "radius of curvature of the two-dimensional spherical universe", and the half-circumference of the circle 4—for example, from M to A—the "radius of the universe".

. . . . .

So much for beings of two dimensions. But what of us three-dimensional beings? Well, we are willing to swear that our universe is three-dimensional, and that with the best will in the world we cannot imagine a fourth dimension. Even our mathematicians cannot do that; just as their two-dimensional colleagues could not imagine a third dimension, although it "existed".

Yet, just as the two-dimensional mathematicians found themselves compelled to invent a more "universal" geometry, which deviated from the usual geometry, so, in the course of the last hundred years, our great mathematicians have been obliged to create a new geometry. The old geometry did not adequately express their ideas, so that Gauss, the "prince of mathematicians", Riemann, Minkowski, and others worked out a more universal geometry, of which little was thought at the time, but which to-day is regarded as the summit of human ingenuity.—They introduced *time* as the "fourth dimension", and thus at least made it possible to obtain an intelligible conception of a "four-dimensional universe". Three-dimensional "space" is as it were "imbedded" in four-dimensional "space-time". In order definitely to describe an "event" we must define its position by means of three dimensions, and we must add the factor of time as a "fourth dimension".—Further, our mathematicians now speak of a "curvature of space", and of "spherical space"; and the reason why they do so will be more apparent if we think for a moment of the measurements of our two-dimensional beings: they do so because in the light of their new theories certain scientific contradictions, certain discrepancies in physics and astronomy, absolutely disappear.

To take only a few examples, which will show us how and why it was desirable and practicable to relinquish the old classical geometry and to apply a new science, let us consider the following: In this new universal geometry the sum of the angles of a triangle

is not 180°; the old proposition that they are equal to two right angles is not therefore false, but is a special case. Let us imagine, on an absolutely smooth earth, the large triangle Vienna—Munich—Berlin, each side being several hundred miles long; it is clear that in this case there will be a slight excess over 180°. Now let us imagine a smaller triangle, whose sides are only a few miles, or even a few yards, in length. Will there still be an excess over 180°? And now, still on the smooth surface of the earth, which we must imagine to be as hard and smooth as a ball of glass, we take a still smaller triangle, whose sides are only a few inches in length. What has now become of the excess over 180°? It has not disappeared; it "exists", but to our practical human understanding it is inconvenient, and we therefore neglect it, though we are still convinced of the superior qualifications of a more universal geometry.

In their application to physics—more particularly, for example, in the related treatment of mechanics and optics—the new methods have been marvellously successful, and in astronomy too have given most fruitful results. What to the uninitiated may seem a complication—for it goes without saying that the mathematical equipment necessary for a more general consideration of the universe seems at first sight far more intimidating than the old and established methods—has really been introduced for the purpose of abolishing, as far as possible, all arbitrary values, and, consequently, all complications.

. . . . .

And thus a "curvature of space" was postulated, not merely as a solution of difficulties, but also in a certain sense as a deliverance from them, and a "radius of the curvature of the universe" was duly calculated.

But this was by no means a simple matter, and the mathematicians had to call on the physicists and astronomers for assistance. In order to understand why this should be so, we must go back to our two-dimensional beings, and imagine them as existing on a world which is indeed rounded, but not spherical; we will imagine it as rather like an egg in shape, and on this great egg-shaped world we will set certain humps or protuberances, for we do not wish to give our two-dimensional beings a too "special" world, lest we should afterwards reproach ourselves with having failed to deduce a *general* principle.

. . . . .

We assume, then, that this world has a "knobby" form (Fig. 29). The inhabitants of this world are, as before, two-dimensional, so that they cannot possibly imagine a third dimension; but we must imagine that they are shaped rather like the little red rubber discs which the dealers in picture-postcards employ in order to fix their postcards against the smooth surface of the shop-window. These little rubber discs are slightly hollowed, and when pressed flat against the glass pane adhere to it by reason of the external pressure of the atmosphere.

Our two-dimensional beings must have a form like that shown (in section) at E, but they can also assume

the forms shown at F and G if conditions require that they should do so. When their curvature is in this way slightly reduced they will be conscious of a certain condition of strain which they will, however, be quite unable to explain to themselves; for having no third dimension they cannot say, as we can, that the localities A, B, C possess a smaller radius of curvature, while the neighbourhood of D possesses a larger radius, accordingly as the localities in question approximate to smaller or larger spheres.

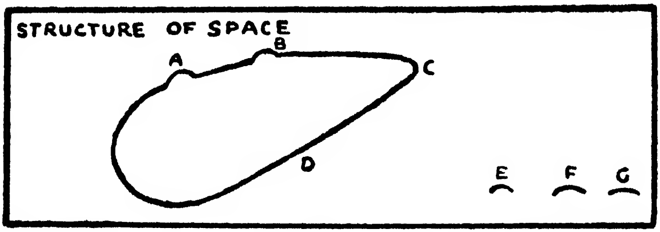

FIG. 29.—Illustrating the "action of Gravitation" in a two-dimensional Universe.

Well, these elastic beings live in a two-dimensional world which extends on all sides of them, rather like a great egg-shell. The inhabitants of this remarkable world are at first, let us say "at the beginning of the world", scattered all over its surface; and they creep about their world, here, there, and everywhere, without ever dreaming that it can be anything other than flat and infinite.—It so chances that one of these beings arrives at C, at the sharp extremity of their irregular egg-shaped world. Here, though he does not know why, he feels quite exceptionally comfortable. He will

talk nonsense about "a good climate"; he will invent all sorts of reasons for his well-being, without ever hitting on the right one; he will write to all his relatives, telling them to come at once to C, as there is no place like it; so that in a very short time a whole crowd of elastic beings will collect about C, just "as though C possessed a power of attraction". The fact that such a "power" exists will be substantiated, though none of the two-dimensional beings has any knowledge of the reason *why* the point C "attracts".

We three-dimensional people, who in comparison with the two-dimensional beings are enormously clever fellows, can readily explain why the latter should feel more comfortable at C, and similarly at A and B. These beings have, as shown in the section E, a perfectly definite normal curvature of body. Now, as it happens, the surface of their egg-shaped world has, at C and A and B, this same curvature. At these points the inhabitants fit their world without straining their bodies in any way, without subjecting themselves to a certain condition of tension. They all feel perfectly comfortable at A, B, or C, and there or thereabouts they remain. It is quite otherwise with the beings who still remain in the neighbourhood of D. Here they have to press their bodies flat against the almost perfectly flat surface, which causes them great discomfort. But they do not understand the cause of this discomfort; they talk, perhaps, of rheumatism in the limbs, but in any case they learn by experience that when they come to such a spot as A or B or C this "rheumatism" ceases. And the news of this fact spreads all over the

"world", and the result is that A, B, and C become celebrated health resorts. These points of the world's surface act "as though" they "attracted" our little curved beings. The points A, B, and C are "centres of attraction".

We, as beings of a higher dimension, as "inhabitants" of three dimensions, can readily state the reason for this attraction. It is because of *the structure of space* that the bodies in this two-dimensional world draw together. It is only because a greater curvature in certain places, which may be likened (but only for the sake of comparison) to the *masses* of the stars or planets, that such attraction takes place. On the other hand, this force of attraction affects the inhabitants of the two-dimensional world because they are *curved*. Translated into our three-dimensional language: the bodies of our three-dimensional universe attract one another because our space is "curved"; because Sun, Moon, and stars —and also, of course, the Earth—represent points of greater space-curvature. Consequently, we are able to define an actual "radius of curvature" for *our* space, just as we did for the two-dimensional spherical space; and if we wish we can even define and calculate a "radius of the universe".

According to this theory, then, the structure of our space furnishes an explanation of the mysterious laws of gravity, the explanation being that wherever there is a "heavenly body", a sun or planet, the space there has a curvature which differs from its normal curvature. Such a curvature of space is assumed by Einstein.

. . . . .

"Three apples"—so said the philosopher Hegel—"were responsible for much mischief: the apple of Eve, the apple of Paris, and the apple of Newton." It is a pity that Einstein, instead of his "relativity mollusc", was not able to add a soft and elastic apple to this collection of examples; we should then have had a "fourth apple".

. . . . .

I have been less concerned to give you a glimpse of the new views concerning the nature of gravitation than to show you, before these talks are finished, that it is quite possible to bring the curvature of space, of which we ought finally to be convinced, into direct relation with the masses, the heavenly bodies, which exist within the universe. If we wish to reach an estimate of the magnitude of the "radius of curvature of the universe", and to express it in miles or kilometres or light-years, then the distribution of the masses in the universe is a factor of special importance. —Einstein has worked out a formula for calculating the radius of curvature of the universe. In this formula we find, with other values, the "*density* of the universe": that is, the mean density. Now, this is what is meant by the mean density: if we could distribute all the masses, or even all the atoms, or all the nuclei and electrons, evenly throughout the universe, this enormously rarefied "ultra-gas" would have a calculable density. This density has actually been calculated; most recently—in 1926—by Hubble, who on the basis of a very careful estimate of the matter actually present in space arrived at a value for the mean density of the universe, or

the average specific gravity of the universe. He found this to be 0·000,000,000,000,000,000,000,000,000,0001 gramme, so that the matter of the universe is, on the average, ten quintillion times less dense than water. This stupendously small value occurs in Einstein's formula, which is a fraction, with a denominator and numerator, as the denominator. We know, of course, that the value of a fraction increases in proportion as its denominator diminishes. The long decimal value, as an element of Einstein's formula, gives us, as the radius of curvature of the universe,

85,000,000,000,000,000,000,000,000,000 centimetres;

or in round figures—

1 quadrillion kilometres, or
100 milliard light-years.

. . . . .

And now, with the end of the book, we have come also to the end of the universe! So vast is the universe that light itself, which in a single second could be reflected seven to eight times round the circumference of the earth, must take a hundred times a thousand times a thousand times a thousand years to speed across it.

. . . . .

In our infancy the universe extended only so far as our arm could reach, and we tried to grasp the Moon. Later in our childhood the heavens were arched above

the neighbouring hills. The whole universe was not much larger than the landscape which one knew. Thus it was when we still played upon our mother's lap. Thus it was in the childhood of the world. But in course of time men began to estimate the distance of the Moon and the Sun, and as time went on the distances increased. Next came the problem of the fixed stars. At first it was believed that the fixed stars, no matter how distant they were, would yet be so near, seen through the telescope, that the movement of the Earth round the Sun would be reflected in the perspective displacement of the stars. Centuries passed, and in the end, as we have seen, it was found possible to demonstrate such displacements only in the case of the *nearest* stars. The most remarkable statistical methods were devised for determining the structure of the Milky Way. Distances of 30,000 light-years were demonstrated; then distances ten times as great. The distance of the remote spiral nebulae was measured. "Thousands of light-years" was the first estimate; now we reckon in a milliard of such units, and to-day we have a formula for calculating the "radius of the curvature of the universe". The universe has indeed no limits; one can move about it at will without coming to the end of it; yet its volume, its content, is finite. "The universe is unbounded yet finite".—And we arrive at a value for the radius of curvature of the universe —or, to put it more simply, for the distance of the end of the universe—of a hundred milliard light-years.

We will accept this figure, without surrendering our

right to believe that later generations may consider that even this estimate is too modest.

We have now reached a position which many of us may find distasteful. It is utterly impossible for us to *think*, to conceive, to imagine all this. Well, it may be some consolation that we are all in the same case. Even the most brilliant thinkers are quite unable to *imagine* these new limits of the universe, though they may have been deduced from actual knowledge of experienced facts. But need this confession diminish our respect for the results which have been attained? Let us remember, once for all, that people used to say that space was endless and infinite. Is there anyone who has even the vaguest idea of what this means? And have we ever been seriously perturbed by our inability to understand it? We quietly accepted the doctrine of "the infinity of the universe".

We have, then, to choose between two possibilities: One is, that the universe is, as we always used to be told, though we could not by any means grasp the idea, *infinite* in all directions. The second possibility has been dealt with in this chapter: the universe is *finite*. The first alternative can hardly be regarded as more than a doctrine of perplexity; the second alternative is recommended to us by the most eminent physicists and mathematicians, who, in accepting this doctrine, have so far attained the best practical results. —It is for you to choose!

For my part, if I have to choose between these two

possibilities—neither of which can be grasped by the imagination—I accept the second:

"The universe is in fact unbounded but finite."

. . . . .

And now my talks are at an end.—"If knowledge were vouchsafed to me under the condition that I should lock it up within myself and should not give it forth, I would refuse it." Despite the words of Seneca, I have one little misgiving: that I have sometimes said things that I should rather have kept to myself!

INDEX